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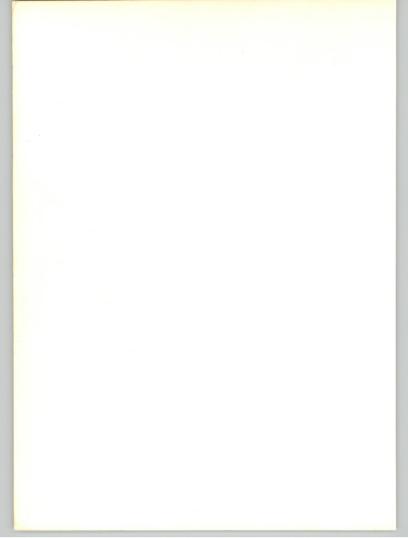
SOME CHARACTERISTICS OF FARM IRRIGATION WATER SUPPLIES IN THE SAN JOAQUIN VALLEY

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CALIFORNIA AGRICULTURAL EXPERIMENT STATION GIANNINI FOUNDATION OF AGRICULTURAL ECONOMICS

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FOREWORD

This report grew out of a broad study of on-farm irrigation under the California Agricultural Experiment Station Project Numbers 1641 and H-1863. Titles of these projects indicate their objectives and subject matter; Economics of Adjustments on California Cotton Farms, and Effects of On-Farm Irrigation Water Supplies and Costs on Cropping Systems and Production Adjustments. Analytical results from studies under these projects appear elsewhere. These analyses involved a great deal of data, some of which we drew from secondary sources; other parts of which represented primary data, although we may have obtained even this information through the cooperation of some other agency. But much of this factual information has value for uses beyond the scope of these original studies, and should be made available in a form suitable for such uses. This is the purpose of the present report; it brings together in convenient form a wide range of information on both ground water and surface sources in the San Joaquin Valley. Some of this information appears in tabular form, other portions are mapped. Parts are fairly complete for given areas, other parts represent a sampling.

We are indebted to many agencies and individuals without whose generous cooperation neither this report nor the more analytical studies, supported in part by these data, would have been possible. Among these we can list only a few of those upon whom we relied most heavily. The major power companies serving the San Joaquin Valley, Pacific Gas and Electric, and Southern California Edison, authorized us to use well test data previously released to the United States Geological Survey. The latter agency also aided greatly in this procedure by making photostatic copies from office records. The California Regional Water Pollution Control Board made well driller reports available to us (data for individual reports are not identified in order to keep both of these sets of

information confidential). The California Department of Water Resources also assisted greatly in these studies by making maps, reports, and other information available, as did the United States Bureau of Reclamation. The California Irrigation Districts Association, many individual irrigation districts, and various manufacturers and distributors of irrigation pumps and equipment provided much valuable assistance in the form of factual data and interpretation. We, of course, drew heavily on published reports and releases of the agencies named here, plus many others.

Among the many individuals to whom we owe appreciation, we wish to mention particularly Messrs. R. S. Ayers, Wm. Balch, D. E. Butler, J. S. Gorlinski, E. J. Griffith, H. H. Holley, G. V. Hufford, J. M. Ingles, F. Munz, B. M. Smith, H. M. Stafford, S. T. Stairs, L. Stennett, and H. D. Wilson. A complete list would extend to a much greater length; we stop at this point only because of space limitations.

As indicated above, this report resulted from studies under two Experiment Station projects. The University of California Water Resources Center contributed an important fraction of the funds used in financing these studies, through its grants for research under Project H-1863.

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SOME CHARACTERISTICS OF FARM IRRIGATION WATER SUPPLIES IN THE SAN JOAQUIN VALLEY

Charles V. Moore and Trimble R. Hedges

INTRODUCTION

Wide differences in irrigation water supplies and costs characterize the San Joaquin Valley. These differences react strongly on cropping programs and farming systems and practices, and, consequently, on farm earnings and profits. Any studies concerned with farm firms in this area, either individually or in the aggregate, must consider both the physical and economic characteristics of irrigation water. Facts about water supplies and cost elements are essential for this purpose.

OBJECTIVE

The objective of this report is to assemble and present in convenient form both physical and economic data related to irrigation water supplies and cost in the San Joaquin Valley. It includes information for both surface and ground water sources. 2/

CHARACTERISTICS OF THE STUDY AREA

The San Joaquin Valley in California is bounded on the north by the Sacramento-San Joaquin Delta, on the south by the San Emigdio and Tehachapi mountains, on the east by the Sierra Nevadas, and on the west by the Coastal Range. Climate in this area varies from arid in the south to semiarid at the

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^{2/} Portions of these data appeared earlier in <u>Galifornia Agriculture</u>, published by these same authors. "Irrigation Pumping Plant <u>Characteristics</u> in the San Joaquin Valley," Vol. 13, No. 3, August 1960; "Irrigation Costs of Pumping in the San Joaquin Valley," Vol. 3, No. 10, October 1960; and "Surface Water Deliveries and Costs in the San Joaquin Valley Cotton Area," Vol. 15, No. 3, March 1961.

northern extremes, with average annual rainfall diminishing from northeast to southwest. The longtime average precipitation for Modesto in the northern part of the Valley is 14.11 inches per year; Bakersfield, at the southern end, has an annual average of 6.91 inches. 1/2 The western portion of the Valley located in the rainshadow of the Coastal Range is drier than Eastside. Average annual rainfall at Huron in western Fresno County is 5.80 inches while the annual average at Visalia in Eastside is 9.45 inches.

The above rainfall pattern has considerable influence on local irrigation water supplies, including both ground and surface sources. Precipitation is not important as a direct source of water for summer crop production. Its seasonal and year-to-year variations, however, critically affect stream runoff in the mountains and recharge of the underground water basin from which farmers pump well water.

Climatic conditions, other than precipitation, in certain parts of the Valley produce an ideal environment for growing certain crops and fruits. Irrigation makes such production possible, and these crops have tended to concentrate in these localities.

The soils of the Valley are primarily recent alluvium, with some lake basin soils. Some of these soils, depending upon how and when they were deposited, contain such high concentrations of calcium and sodium that they are unproductive for agriculture.

Fruit, nut, and vine production is concentrated east of the Valley trough on a north-south axis. This subarea includes 36 percent of the state's total fruits and nuts acreage.

Almost all San Joaquin Valley cotton production occurs south of the southern border of Merced County. Mean daily temperatures north of this line are too low for profitable commercial cotton production.

 $[\]underline{\mathbf{J}}\!\!/$ Calculated by the authors from United States Weather Bureau reports.

The supply and development of irrigation water influences farm size in the Valley. Farming first developed along the Eastside with small farms predominating, as they still do, in this subarea. Limited water supplies available from streams, and the inability of settlers to finance larger farms, dictated these small operations. Lend-development companies originally owned much of the land on the Eastside; they in turn sold it to settlers. These companies subdivided their sizable tracts into small percels for quick sale. As land development continued streams were no longer adequate as a dependable source of water for summer irrigation. Conservation storage dams on some of these streams were too costly for local groups to finance. In 1902, with the passage of the Reclamation Act, help became available from the Federal Government. Along with Federal aid, however, came the "160-acre limitation." The results were to ration the supply of surface water among users; and greatly to decrease the opportunity for farmers to expand farm size in this subarea.

Large scale development in the western and southern portions of the San Joaquin Valley did not occur until after World War II. At this time, the deep well turbine pump, and relatively high cotton prices, made it economically feasible to lift water from deep underground reservoirs for irrigation (see Figure 1). Capital and acreage limitations did not restrict development in these areas; extremely large-sized farms, therefore, are characteristic here.

Physical Characteristics of Irrigation Pumps and Wells

The major electrical power companies serving the San Joaquin Valley test customers' pumps without charge. This analysis uses the results from 11,000 such tests, ranging from Stockton to south of Bakersfield, during the period 1949-54

(see Figure 2). Data available for each pumping plant test include the plate and input horsepower, static depth, pumping depth, and total lift, as well as pump discharge in gallons per minute and temperature. — From these data, the power companies calculated over-all plant efficiency, drawdown, kilowatt-hours per acre-foot, and specific capacity of the pumping plant.

Arithmetic means for some of these characteristics, by geographic townships, are available; we present these data in Table 1.

The information in Table 1 indicates considerable variation in pumping plant characteristics even from as small a geographic area as one township to the next. These results are reinforced by interviews with well drillers, farmers, and pump company personnel working in the San Joaquin Valley.

Total pumping lifts are smallest in the northeastern part of the Valley and tend to increase from east to west and from north to south following fairly closely the annual rainfall pattern.

We considered the number of pump tests per township adequate for most purposes except in the Tulare Lake basin area. Here the large farming corporations test their own wells, thus sharply limiting the number of power company tests, and hence, the information available to us.

1/ Definitions for terms used in this section are as follows:

Static depth - distance from the center of the pump head to the surface of water in the well when the pump is not operating.

 $\underline{\underline{Pumping~depth}} \ - \ \text{distance from the center of the pump head to the surface}$ of water in the well when the pump is operating.}

 $\underline{\text{Total lift}}$ - distance or pressure measured in feet from the center of the discharge $\underline{\text{pipe to}}$ the water level when the pump is operating.

<u>Input horsepower</u> - kilowatt input divided by .746.

Over-all plant efficiency - motor efficiency multiplied by pump efficiency.

Drawdown - difference between static lift and pumping lift.

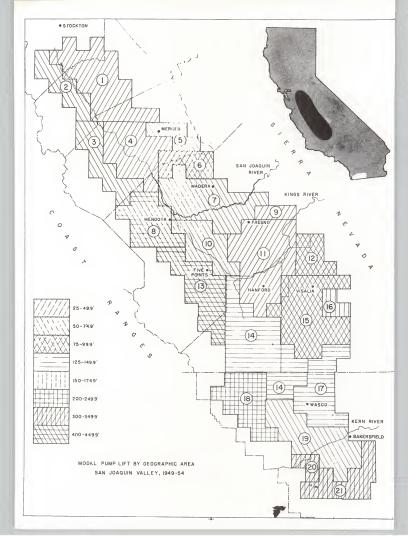
Kilowatt-hours per acre-foot - are determined by the formula:

1.024 x total lift
over-all plant efficiency

Specific capacity - represents g.p.m.

drawdown

Plate horsepower - is the manufacturer's horsepower rating.



Township (Mt. Disblo	Number of tests	Plate horse- power 2	Static depth	Pump depth	Draw- down	Total lift 6	G.Р.М. 7	K.W.H. per sore-foot	Dwer-all plant effi- ciency	Township	Number of : tests	Plant horse- power 2	Static depth 3	Pump depth	Drav- down	Total lift 6	о.р.м. 7	K.W.H. per acre-foo	Over-a plant effi- toiency
Mt. Diablo mae Maridian)										712 R11	27	152.8	231.4	307.9	30.6	310.7	1483+7	529.9	60.6
1 87 88 89 R10 R11	25 21 61 15 4	15.4 22.1 24.0 25.0 45.0 30.0	20.5 13.7 29.6 51.7 81.2 45.1	43.8 38.6 49.4 67.4 107.2 110.6	27.2 19.5 16.3 14.4 17.5 25.9	45.5 39.9 50.4 68.4 109.0 110.8	789.4 1389.5 1204.2 929.7 1261.2 685.0	88.5 74.1 95.2 124.1 175.0 184.5	51.8 54.6 53.2 56.6 63.8 60.5	R12 R13 R14 R15 R16 R17 R18 R19 R20	13 6 2 44 31 95 86 38 38	118.1 79.2 62.5 31.7 25.3 19.4 20.8 22.8 13.8	208.3 152.2 25.0 34.3 61.0 67.8 77.1 72.5 49.3	268.4 211.1 61.8 56.6 80.1 81.1 86.2 85.0 58.2	36.2 52.0 36.9 21.6 19.3 13.2 9.1	271.4 230.8 64.8 59.0 81.0 83.7 88.0 88.5 61.7	1305.5 841.8 2615.0 1490.2 834.8 612.7 617.3 763.2 626.3	451.0 470.4 117.2 102.7 150.1 170.4 165.2 156.8 125.8	61.4 49.5 56.5 58.9 55.5 53.7 54.9 50.1
R5 R6 R7 R8 R9 R10	6 13 10 6 8 7	65.8 46.2 27.7 15.5 24.4 49.3	51.7 15.9 11.2 20.2 30.0 77.2 80.6	97.3 87.0 37.6 28.8 49.9 95.4 118.5	16.4 19.8 17.0 12.0 20.8 16.2	143.9 87.6 40.2 33.3 52.6 96.2	1539.2 1313.1 1302.0 1029.2 1287.5 1336.9	220.6 159.5 83.2 64.6 92.6 164.7	56.5 54.0 50.1 50.7 57.0 59.1 64.2	R21 R22 R25	57 4 11	11.5 6.5 9.9	51.4 44.2 31.7	68.1 64.4 55.6	15.5 15.4 31.2 22.3	69.9 65.2 69.8	426.3 238.8 245.1	147.8 148.1 164.6	49.3 44.8 45.6
R11 R12	10	50.0 46.7	80.6 53.4	118.5	19.7	120.0	1240.0 1413.3	189.2 170.0	64.2 65.3	R12 R13 R14	26 23 15	202.9 138.0 90.7	365.7 357.5 211.4	435.0 390.5 201.4	41.4 40.2	437.9 393.5 204.3	1510.3 1024.2 1702.8	673.8 737.4 377.0	64.7 55.9 58.9
3 R5 R6 R7 R10 R11	10 20 1 2	112.5 68.0 10.0 50.0 53.3	55.4 25.3 	192.3 138.9 9.1 84.6 118.5	35.1 24.4 23.2 12.0	195.0 140.4 12.0 86.0. 119.5	1370.0 1192.4 805.0 1542.5 1251.7	380.6 292.0 48.4 140.5 199.3	50.4 52.5 25.0 62.5 60.7	R15 R16 R17 R18 R19 R20 R21	35 33 69 73 58 59	37.9 27.3 18.5 13.2 10.4 22.4 11.3	47.8 36.6 43.4 44.9 47.5 41.9 29.3 29.3	67.7 57.8 59.3 54.8 55.7 51.9 42.3 44.2	19.9 20.7 15.4 9.9 8.7 9.8 12.8	69.6 57.3 61.0 56.8 58.0 61.1 45.1 48.2	1645.3 1204.2 870.1 587.2 438.1 747.3 651.0	112.5 105.4 113.0 113.5 123.0 155.2 93.5	62.7 58.1 55.1 51.9 49.8 49.8 51.6 46.3
26 27	3 5	85.0 39.0		169.4 58.5		174.0 58.7	1263.3	324.0 99.1	51.3 60.2	R22 R23	65 7	9+3 5+4	18.3	41.9	15.2 23.6	46.9	149.0	113.9 150.3	32.9
5 R7 R13	6	81.7	39.8	136.3 75.3	35.5	144.4 76.3	1780.8 2622.0	242,2	58.7 57.0	T14 R12 R13 R14 R15 R16	14 81 41 7	210.7 222.6 128.7 85.0	489.9 476.8 296.6 142.2	519.3 513.9 334.5 199.4	30.2 25.1 36.2 28.5	555.8 516.8 346.3 202.4	1287.8 1387.9 1163.9 1369.9	879.1 770.8 588.1 366.3	64.8 64.8 61.1
87 88 89 R11 R12 R13 R14	21 22 22 9 5	75.0 68.6 40.0 23.5 29.4 17.6 10.0	85.0 38.7 35.5 38.7 21.1	325.6 141.5 58.5 45.3 53.6 58.5 47.4	15.4 17.9 19.8 26.3	332.3 145.0 58.8 48.2 57.3 62.3 47.4	695.0 1098.5 2000.0 1115.0 1139.2 683.4 214.0	619.0 278.8 100.5 95.3 110.3 126.3 253.7	54.0 55.3 59.5 51.9 52.6 51.0 19.0	R16 R17 R18 R19 R20 R21 R22 R23 R24	14 62 99 77 79 107 80 18	38.9 17.2 16.9 15.2 15.0 9.9 11.2 12.7 7.9	37.1 41.4 40.9 31.8 28.2 30.2 31.3 43.7 54.8	58.8 55.5 53.3 41.2 37.7 39.0 43.9 58.4 73.3	20.8 14.5 12.6 10.1 10.5 9.1 12.7 16.6 18.5	59.8 56.5 54.4 43.7 41.8 43.0 49.3 62.3 77.0	1719.6 852.6 872.1 925.2 847.8 569.3 531.7 516.6	110.7 102.8 99.8 82.9 83.4 89.3 104.1 132.1	55. 56. 54. 52. 50. 49. 46.
R6 R9 R10 R11 R12 R13 R14 R15	19 4 1 15 3 4 1 2	45.0 32.5 5.0 35.3 26.7 7.8 20.0 12.5	43.0 31.4 7.6 16.2 11.1 16.6 21.7 25.6	79.9 63.9 37.0 40.0 32.9 30.9 53.1 42.2	18.7 15.1 29.4 23.8 21.0 14.2 31.4 16.6	82.3 64.0 37.7 42.9 36.6 33.5 54.2 43.4	1392.6 1563.8 230.0 2096.6 1677.0 497.0 1059.0 744.5	157-5 99.8 107-5 79.8 71-5 75-9 93.0 278.8	55.2 65.8 35.0 55.1 52.7 46.5 60.0 51.5	T15 R13 R14 R15 R16 R17 R18 R19 R20 R21	2 22 21 46 88 31 114 130 74	225.0 12747 99.5 36.1 43.0 31.1 16.5 12.0	341.8 152.5 68.8 64.3 39.7 41.0 35.5 28.3	598.5 394.2 208.9 86.8 85.3 57.2 54.1 47.5	36.5 40.2 19.0 22.4 16.6 13.5	601.5 397.1 221.9 87.5 87.9 58.7 56.5 52.1 42.5	1181.0 1089.4 1500.6 1228.7 1511.5 1222.5 791.2 680.2	905.3 576.7 359.3 147.1 139.4 116.9 108.4 98.1 92.2	68.5 63.5 59.5 61.3 64.6 57.5 54.2 54.1
RS R9 R10 R11 R12	5 11 4 2 5	29.0 28.6 52.5 50.0 21.0	32.5 44.6 64.0 20.0 19.2	94.2 71.6 112.6 56.6 50.1	37.6 37.4 14.2 36.6 30.9	94.5 71.9 114.1 59.2 52.2	838.0 1022.3 1340.0 2351.0 1194.8	179.0 127.7 193.1 108.5 95.7 144.3	53.6 57.6 59.5 50.5 55.0	R22 R23 R24 R25	53 44 61 6	10.3 11.7 16.6 13.5 11.3	32,6 51,4 58,1 74,2	39.3 44.9 62.7 73.5 129.8	11.2 12.2 11.2 15.9 55.6	47.1 73.1 77.0 154.6	590.5 637.6 516.3 251.5 147.7	90.7 151.9 235.1 397.6	52.5 50.2 40.5 39.5
R13 R14 R15 R16	9 5 46 32	25.0 21.0 23.5 16.9	11.5 40.7 38.9 38.4	33.9 56.6 65.1 70.1	22.4 15.9 24.3 31.7	35.4 59.0 66.7 71.8	1611.6 826.6 900.9 615.2	144.3 124.1 129.5 145.3	52.0 48.8 54.8 52.5	R14 R15 R16 R17 R18	21 21 11 30	179.5 157.4 106.8 62.0 41.3	184.2 109.9 65.9	499.1 403.6 221.9 135.8 84.6	16.2 59.9 33.0 25.0 18.6	501.5 406.6 224.9 138.8 86.0	1234.7 1151.7 1644.5 1471.1 1197.4	807.5 689.7 381.3 225.4 161.3	63.8 59.2 61.7 64.8
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R17	11	18.1	67.0		25.6 22.8	93.7 69.1	831.8 490.9	165.1 149.9	43.9	T17 R15 R16 R17	30 27 24	250.8 150.0 99.6	379.5 361.0 241.8	600.8 391.5 279.4	221.3 30.6 34.4	604.7 394.5 282.4	1305.3 1182.6 1144.3	1000.9 653.9 458.2	61.8 61.6 62.8
R9 R10 R11 R12 R13 R15 R16 R17 R18	36 36 24 16 43 113 68 72 22	26.2 26.2 32.9 31.9 33.0 24.2 20.5 19.6 22.0 18.0 22.5	37.3 37.3 32.6 17.6 24.4 52.4 66.9 80.0 75.4 36.9 32.2	60.6 60.6 57.0 48.4 57.5 68.4 80.0 98.1 93.0 55.9	21.0 21.0 24.9 30.8 32.7 16.1 14.1 17.9 17.7 21.0 19.8	62.8 58.5 59.1 59.3 70.5 81.6 98.3 94.6 57.3	1219.6 1219.6 1631.3 1750.0 1526.5 980.9 713.6 520.5 631.4 846.8 1197.8	234.2 118.2 99.7 89.8 105.7 128.1 150.7 196.2 180.4 105.1 97.3	48.0 56.7 59.3 56.6 57.6 56.1 52.4 55.5 54.6 57.2	R18 B19 R20 B21 B22 B23 B24 B25 B26 B26 B27 R28	33 1/2 27 22 35 28 37 125 166 7	56.7 24.2 15.5 15.0 12.9 14.4 17.1 11.3 10.0 4.0 3.0	107.2 47.6 33.3 29.7 24.1 23.2 19.9 70.0 61.6 27.1 50.7	139.3 71.9 51.6 44.4 37.0 34.8 34.9 85.3 77.1 84.8 57.4	22.9 24.0 20.2 16.0 14.7 11.5 15.3 15.2 15.8 57.9 6.7	142.0 75.9 53.9 47.4 41.3 37.8 37.8 89.0 83.9 92.0 60.0	1223.3 917.5 741.9 833.6 822.7 948.1 1148.0 326.7 254.4 113.3 76.0	251.2 129.2 110.6 88.8 80.4 74.5 75.3 202.0 201.5 265.8 1865.1	61.0 55.8 51.2 54.8 53.0 51.7 47.5 44.1 41.4
R10 R11 R12 R13 R14 R15 R16 R17 R18	34 31 22 14 17 38 119 115 59 3	43.4 100.3 32.7 31.6 37.4 20.9 21.3 19.4 15.9 160.0	110.9 152.0 18.7 13.1 31.5 33.2 68.2 65.1 65.0 319.1	134.5 199.6 49.1 40.8 57.5 48.4 85.4 81.8 82.4 339.6	24.9 36.8 33.0 26.8 25.4 15.2 17.2 16.4 17.1 20.5	139.9 201.7 50.9 42.6 59.5 50.3 87.2 84.1 83.6 342.0	889.6 1523.2 1646.1 1776.9 1523.6 1154.2 643.5 589.3 447.1 939.0	239.6 321.1 94.4 75.5 111.7 99.5 169.1 162.3 173.1 505.4	57.4 63.9 55.0 51.1 \$4.8 53.2 53.9 53.8 50.2 63.7	T18 R16 R17 R18 R19 R20 R21 R22 R23 R24 R25 R26 R27	13 34 25 11 11 23 13 33 116 182 254 105	205.8 160.3 108.6 56.4 11.9 12.4 21.5 18.5 15.3 10.7 10.4 8.8	427.9 339.8 313.5 88.3 34.0 39.5 37.3 61.8 47.1 40.6 64.6	546.9 419.0 310.8 137.3 54.1 55.2 54.4 76.1 59.2 78.1 82.5	119.0 26.8 30.3 34.8 22.6 15.7 17.1 14.4 12.2 9.6 13.6	549.9 422.0 313.6 139.2 58.9 56.8 56.0 78.3 61.5 54.3 82.1 89.7	1205.8 1134.0 1021.0 981.7 374.5 554.0 884.7 623.2 651.7 495.8 304.7	1009.6 759.4 552.5 245.0 151.0 114.3 108.5 156.2 136.0 121.4 185.2	61.5 59.4 58.9 56.5 40.3 51.6 54.5 51.6 50.0 45.9 40.3

(Continued on next page.)

Township	Number of tests	Plate horse- power	Static depth	Pump depth	Draw- down	Total lift	G.P.M.	K.W.H. per sere-foot	Over-all plant effi- ciency	Township	Number of tests	Plate horse- power	Static depth	Pump depth	Draw- down	Total lift	G.P.M.	K.W.H. per scre-foot	Over-all plant effi- ciency
T19 R16 R17 R18 R19 R20	1, 11 23 6	237.5 250.0 225.0 76.7 62.5	611.8 511.7 368.1 145.7 91.6	614.0 496.5 413.7 251.3 128.0	82.8 33.1 41.4 30.5 36.5	617.0 499.3 416.7 253.9 132.9	1206.0 1524.5 1673.1 922.8 1159.2	950.5 798.7 561.8 439.5 199.8	66.0 60.2 59.7 58.7 59.8	T27 R22 R23 R24 R25 R26	25 60 159 71 34	66.0 78.0 40.2 71.0 102.2	128.6 143.9 146.2 168.0 266.5	157.3 158.9 160.6 182.1 290.8	28.0 16.1 14.7 14.1 24.7	158.6 166.6 165.7 187.9 297.0	1258.8 1339.1 653.7 1058.6 1064.2	287.1 294.9 328.3 352.9 512.8	58.0 58.4 54.1 55.9 59.6
R21. R22. R23. R24. R25. R26. R27	5 15 103 171 177 334 5	20.6 22.3 24.2 22.5 15.4 14.5 8.6	67.1 51.2 78.2 80.5 46.2 109.3 115.6	96.3 75.4 92.2 92.8 58.5 122.8 123.6	29.2 23.4 14.3 12.7 12.3 13.6 7.2	98.3 76.4 94.5 95.5 60.9 126.8 129.3	543.4 756.5 699.8 625.8 600.0 308.4 136.2	197-5 161-7 179-3 188-4 130-7 267-4 351-0	49.6 52.1 54.3 53.3 48.6 47.2 33.0	728 R22 R23 R24 R25 R26 R27 R28	16 12 74 214 82 24	27.4 47.9 42.9 33.3 103.3 133.8 110.0	78.6 83.6 110.7 120.8 226.9 312.5 125.4	105.4 97.0 122.9 131.8 243.2 321.6 153.3	22.4 13.4 12.0 10.6 21.5 18.5 27.9	109.3 101.2 128.1 136.4 248.2 338.3 158.0	1005.5 1289.8 935.6 674.8 1287.3 1118.1 1782.8	256.9 181.4 247.8 260.9 442.4 637.7 285.9	48.3 55.7 55.0 55.1 57.7 56.1 56.3
R15 R16 R17 R18 R19 R20 R21 R22	28 14 2 23 19 2 8	78.2 105.4 250.0 182.6 113.4 112.5 143.8 45.0	206.2 162.6 506.1 55.8 238.2 178.7 142.5 74.2	239.4 278.2 583.0 432.9 278.9 205.4 205.0 109.4	36.8 37.4 90.4 44.6 31.2 26.6 37.2 32.9	274.0 586.0 435.9 280.7 207.4 207.0 110.8	900.6 989.1 1498.5 1271.5 1256.6 1739.5 2037.1 1166.2	934.5 740.8 470.0 311.4 338.3 185.6	60.3 56.9 64.5 61.0 60.9 68.0 62.6 60.9	R32 T29 R22 R23 R24 R25 R26	1 20 17 45 34	60.0 49.2 46.2 25.8 19.1	52.3 56.7 54.7 57.0 45.9	74.5 74.8 75.5 70.0 55.1	22,2 18.0 20.8 12.9 8.6	75.0 76.9 79.3 74.5 58.7	2835.0 1849.6 1552.2 945.7 795.6	112.0 132.8 144.3 142.9 115.3	61.0 64.0 59.5 56.1 54.1 52.7
R23 R24 R25 R26 R27	151 167 125 296 97	24,4 20.0 22.2 18.3 14.2	94.8 78.7 67.0 191.4 219.7	107.4 92.0 85.9 212.3 255.6	12.6 13.0 17.8 22.2 35.9	94.7 88.5 214.6	583.8 494.9 628.8 225.6 122.8	211.6	52.4 48.7 49.7 47.5 44.9	R27 R28 R29	17 15 14	29.1 43.1 89.6	87.8 183.1 304.8	110.4 224.3 361.5	22.5 41.2 56.7	114.3 229.2 366.0	629.7 669.1 691.9	452.3	50.2 52.6 58.3
721 R15 R16 R18 R19 R20 R21 R22	14 31 13 17 22 5 51	73.2 55.0 130.8 95.9 169.3 88.0 42.7	168.6 138.8 279.1 245.4 207.0 154.7 87.7	214.5 184.4 342.7 287.8 241.7 185.3 117.7	62.4 29.6 25.4 30.5 30.0	243.5 186.5 120.2	944.2 839.4 1115.2 915.8 1970.5 1272.8 827.5	338.5 567.1 517.5 424.3 336.8 236.4	57.0 56.6 62.7 59.0 60.0 58.4 50.8	#30 #2% #25 #26 #27 #28 #89 #30	5 7 5 52 40 81 22	48.0 39.3 22.0 25.2 38.2 102.3 121.4	49.2 53.8 35.3 42.9 100.8 277.3 296.4	64.4 74.4 51.3 58.9 121.8 302.4 374.5	82.9	67.1 79.1 56.8 62.9 127.4 307.7 384.8	2111.2 1282.4 1178.2 1062.3 813.3 1008.7 864.6	157.0 102.9 118.1 256.6 540.8	49.2 50.4 56.8 55.1 52.8 58.3 57.3
R23 R24 R25 R26 R27 R28	21. 74 119 183 186 17	47.6 32.0 33.1 25.8 13.6 30.5	82.5 85.5 109.4 91.8 96.0 105.3	130.7 105.5 133.8 108.9 120.0 119.3	26.9 20.0 24.3 19.5 26.5 15.4	123.9	905:0 768.4 674.1 578.3 311.4 471.3	242.3 209.7 260.6 233.3 295.6 284.3	55.9 52.4 53.8 50.5 45.6 47.4	T31 R26 R27 R26 R29 R30	5 39 35 67 28	39.0 28.0 45.9 107.1 144.5	35.3 44.1 86.5 221.6 301.8	242.8	27.6	67.4 118.2 249.7	1722.1 1039.1 1057.1 1280.1 1363.5	7 135.8 7 213.2 5 430.1	51.4 51.7 56.0 61.2 62.3
T22 R18 R22 R23 R24 R25 R28 R28	1 10 42 86 131 150 34	150.0 60.0 59.5 37.3 36.2 35.3 21.4	297.2 99.0 110.8 126.0 154.1 145.6 111.1	366.9 157.8 143.6 145.8 173.7 161.0 144.7	69.7 28.3 31.1 20.7 20.1 15.3 33.6	149.4	1318.0 975.1 1172.3 672.2 550.1 554.7 317.5	312.3 255.6 290.4 379.4	66.0 56.3 60.0 53.7 50.7 53.4 47.4	T32 B24 R25 R26 R27 R28 R29	1 2 10 3 32 57	125.0 87.5 77.5 36.7 121.1 119.3	200.0 225.0 244.4 21.5 183.9 223.7	324.6 310.0 54.4	69.6 65.6 32.8 44.0	327.7 314.8 60.1 233.5	1801,6 610, 685, 1290, 1545, 1400,	5 747.1 647.3 114.9 412.3	66.0 45.5 53.3 53.3 58.3 59.6
223 R23 R24 R25 R26 R27	9 29 123 55 12	53.9 45.0 37.3 65.9 28.3	113.4 112.1 148.1 199.5 257.3	165.9 142.5 174.5 224.4 283.9	49.5 29.9 26.7 25.7 30.4	145.4	868.4 859.0 546.9 852.6 203.8	285.8 370.5 433.3	55.1 55.8 50.9 55.6 47.2	(San Bernardi Base Meridian T12 R22 R21 R20 R19		130.0 125.0 137.9 161.8	229.0	273.0	27.6	276.5	1213.	0 500.0 3 561.0	55.2 57.0 58.6 61.4
R18 R19 R22 R23 R24 R25 R26 R27	7 4 8 6 106 60 12	72.1 93.8 35.0 42.5 31.7 54.2 95.8 67.5	203.5 74.6 116.2 146.7 90.8 190.8 321.1	247.1 224.4 140.0 164.4 129.8 229.8 352.4 403.1	28.0 64.9 23.6 18.2 39.0 36.6 38.4 37.0	227.4 141.8 167.2 132.4 234.6 366.2	803.9 1242.8 497.5 730.9 654.7 592.1 693.9 398.0	379.9 352.4 317.3 262.8 480.0 726.4	55.4 52.2 42.0 55.6 53.0 50.7 52.6 46.1	T11 R22 R21 R20 R19 R18	1 2 10 47 12	250.0 200.0 185.0 205.3 140.4	273.2	345.0 361.1 384.1	71.8 22.	347.8 365.8 389.7	1764.	5 573.6 4 628.0 9 625.8	55.0 62.0 60.4 64.0 57.2
T25 R18 R19 R22 R23 R24 R25 R26 R27	1 9 7 31 37 88 95 9	5.0 79.4 71.4 38.9 49.4 54.1 84.5	30.5 219.9 116.3 123.2 116.5 179.0 330.6 387.9	39.1 308.9 153.4 147.8 141.4 213.4 363.6 443.3	8.6 59.9 37.1 22.4 24.6 28.9 30.8 55.4	42.2 312.0 154.6 150.2 146.9 216.5 366.5	100,0 689,1 994,4 754,1 936,2 666,7 604,4 716,8	93.2 58.6 317.0 270.4 276.4 419.3 711.9	42.0 55.0 52.0 58.7 53.1 53.9 53.7 54.4	TIO RIG	1	75.0	84.0	243.5	159.	245.5	650.	0 481.8	52.0
T26 R18 R22 R23 R24 R25 R26 R26	24 9 27 50 68 62 1	24.6 69.4 44.9 59.3 58.5 85.9 100.0	183.1 110.1 114.2 138.7 219.4 304.8	217.5 143.4 130.1 161.1 242.0 325.2 308.2	36.5 32.7 15.9 21.8 19.8 20.4	134.3 165.6	264.0 1391.8 962.6 1028.9 660.4 764.2 804.0	275.8 250.7 294.0 465.4 596.9	48.8 55.3 55.5 57.9 55.3 57.7 60.0										

Sources: Courtesy of U. S. Scological Survey, Pacific Cas and Electric Company, and Southern California Misco Company; calculations by the authors.

We also grouped townships with similar pumping plant characteristics into 21 hydrographic areas. Mean values for these characteristics by areas appear in Table 2, and hydrographic area locations and boundaries in Figure 2.

Topography and ground water conditions (specific yield) greatly affect the motor horsepower, pump lift, and discharge for pumps in the San Joaquin Valley. The greatest mean pump discharge (g.p.m.) occurs in hydrographic area 4, which area includes the Valley trough area in Merced County. This hydrographic area lies on both sides of the San Joaquin River, and enjoys one of the best ground water supplies in California. Lowest electrical energy requirements per acre foot of water pumped (95.4 kilowatt-hours), is indicated for hydrographic area number 1, immediately north of area 4. This area includes that part of Stanislaus County extending from the San Joaquin River to the foothills of the Sierra Nevada mountains.

The highest horsepower pump motors occur in area 13, including the western portion of Fresno County around the Five Points area. Highest electrical energy requirements per acre-foot (747 kilowatt-hours), however, are in area 21 near Ford City, western Kern County. The number of pump tests (2) in this latter area was very small, however, and the data, therefore, are not statistically reliable as a sample of the entire area.

TABLE 2

Mean Pumping Plant Characteristics by Hydrographic Area,
San Joaquin Valley, 1949-54

Area	Plate horse-	Static	Pumping	Draw-	Total	a 2 v	K.W.H. per	Over-all plant	Number of
number	power	depth	depth	down	lift	G.P.M.	acre foot	efficiency 8	tests
	1	2	3	4	5	6	7	0	9
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21	24.6 68.1 65.0 30.9 20.0 22.6 19.9 147.4 40.0 14.4 173.7 67.3 22.5 163.0 40.1 41.2 87.5 129.2	30.4 49.1 89.2 28.8 37.1 63.0 55.5 290.3 290.6 58.0 83.8 124.2 83.8 127.3 179.5 81.8 203.3 179.5 81.8 255.0 262.6	48.6 129.8 141.1 57.6 64.7 80.9 364.1 43.0 73.8 426.6 170.9 101.1 177.0 225.0 237.5 99.9 324.6 288.6	18.7 26.6 28.2 27.8 26.4 17.0 14.0 38.5 14.1 20.5 13.3 16.1 38.0 27.5 17.4 20.1 22.6 8 17.7 69.6 26.8	50.5 132.7 144.0 59.3 66.3 81.7 72.1 371.6 46.2 92.5 52.6 79.0 429.6 173.8 104.5 179.5 230.3 241.1 104.1 327.7 295.5	1211.1 1298.9 1291.2 1469.9 772.5 771.0 754.4 1288.4 1286.4 1246.6 693.4 1020.7 551.9 249.9 763.8 452.2 1095.0 610.5 1334.5	95.4 256.8 247.7 110.0 136.0 155.0 140.8 606.5 102.9 159.0 103.7 194.0 728.2 318.1 220.6 423.8 442.6 501.5 198.1 747.1 507.8	53.4 54.6 58.2 56.2 53.5 54.0 60.3	213 83 166 191 85 386 1,233 205 184 391 1,420 275 2,591 727 1,192 34 511 2 337

Sources: Courtesy of U. S. Geological Survey, Pacific Gas and Electric Company, and Southern California Edison Company; calculations by the authors.

These same hydrographic areas provide the basis for sorting the 11,000 pump tests according to total lift. We used class intervals of 25 feet for this grouping within the range from 0 to 199.9 feet and 50 feet for the range from 200 to 500 feet (see Table 3).

Total pump lifts are lowest in the northeastern part of the San Joaquin Valley, and tend to increase from north to south and from east to west. For the entire Valley, well distribution by total lift was uneven and concentrated around two levels. Heaviest concentration centered around a lift of 63 feet, with a secondary concentration at the 226 foot level and the median lift at 91.7 feet. Thus, there were as many wells with lifts greater than 91.7 feet as there were with less than this lift.

The extremely high lifts on the Westside and in the Wheeler Ridge area heavily weigh the average lift for the entire Valley towards the upper end of the scale; the standard deviation about the 118 foot mean was 102.7 feet.

Over-all pumping plant efficiency averaged 52 percent for the entire 11,000 well sample. It was highest, 62 percent, in the two subareas with the maximum lift and horsepower. This high lift-high efficiency relationship reflects two causal factors: first, slightly higher efficiencies are built into the larger pumps; second, farmers watch operating efficiency and undertake to improve it when it drops, because they know that a slight decrease in efficiency sharply increases costs when pumping from extreme depths.

			He	an Pumpin	g Plant Ch	urscteristi	cs by Hydro	graphic	Area :	and Total Li	ft, Sen	Josquin '	Valley, 1	949-54			
Area	Class interval in feet	Total lift	Pump depth	Plate horse- power	G.P.M.	K.W.H. per acre-foot	Over-all plant efficiency	Number of tests	Area	Class interval in feet	Total lift	Pump depth	Plate horse- pover	G.P.M.	K.W.H. per acre-foot	Over-all plant efficiency	Number of tests
1	0- 24-9 25- 49-9 50- 74-9 75- 99-9 100-124-9 125-149-9	21.6 39.1 59.7 85.9 100.5 127.3	18.8 36.8 58.4 84.4 107.8 125.4	11.8 20.6 24.8 41.8 87-5 100.0	914-5 1217-7 1155-6 1382-6 2220-0 1990-0	63-1 79-0 107-9 144-4 178-0 210-0	38.4 51.0 56.9 61.0 65.5 62.0	12 109 67 22 2	12	0-24.9 25-49.9 50-74.9 75-99.9 100-124.9 125-149.9 150-174.9	17.6 39.0 63.1 87.2 107.2 137.7 163.3	24.8 36.5 59.3 82.6 102.3 127.1	6.5 11.5 12.6 9.9 11.4 11.7 26.0	299.5 686.6 391.4 246.2 254.1 166.8 409.2 140.5	110.8 88.8 159+3 219.2 236.6 504.8 274.4	27-3 46.6 44-5 44.8 48.4 41-1 51-0	6 99 120 167 93 17
2	25- kg.9 50- 7k.9 75- 99.9 100-12k.9 125-1kg.9 150-17k.9 175-199.9 200-2kg.9 250-299.9	36.0 64.8 87.0 111.1 140.1 161.4 191.0 212.9 282.0	31.9 62.7 85.2 109.2 137.8 159.1 186.2 212.5 275.9	18.5 35.0 52.5 60.0 80.0 77.9 85.8 112.5 135.0	843.2 1499.0 1434.0 1356.2 1443.0 1285.8 1210.4 1102.5 1010.0	179.8 120.7 171.8 172.8 266.0 281.7 339.0 551.0	33.8 57.5 52.0 56.2 54.4 58.8 59.8 51.0 52.2	17 10 10 12 13 4 6	13	175-199.9 200-249.9 100-124.9 150-174.9 175-199.9 200-249.9 250-299.9 300-349.9	186.9 214.9 111.4 167.4 184.5 225.6 276.9 323.4 379.9	127.3 127.8 108.4 164.4 181.5 222.6 274.2 320.5 376.9	10.0 35.0 50.0 75.0 53.3 71.2 95.9 118.6 161.1	140.5 453.7 1305.0 1213.5 894.0 906.1 1047.6 1120.3 1324.7	390.7 386.1 187.2 300.8 309.4 386.1 499.3 536.3 574.3 689.1	57.0 60.0 57.0 62.0 57.7 58.7	3 1 2 3 17 17 26 36
3	0- 24,9 25- 49,9 50- 74,9 75- 99,9 100-124,9 125-149,9	18.4 10.0 60.9 86.1 113.8 139.7	16.2 39.3 59.0 84.3 112.6 133.6	26.7 20.4 31.2 39.3 38.8 40.0	1432.3 1317.6 1479.3 1206.6 788.2	53.8 78.4 111.5 154.7 215.9	41.7 54.3 58.8 58.9 54.8	3 29 29 21 13	14	350-399.9 400-449.9 450-499.9 5 500.0	423.9 474.8 600.8	101.0 171.9 597.1 64.5	164.0 204.3 248.0	1333.8 1336.5	743.4	59.9 60.4 61.8 62.5	50 46 63 8
à	150-174.9 175-199.9 200-249.9 250-299.9 300-349.9 '350-399.9 5 500.0	160.2 188.4 226.0 281.0 320.0 365.0 536.8	152.3 180.8 223.8 274.8 317.6 363.6 534.7	50.8 62.8 116.8 113.2 200.0 175.0 250.0	738.0 947.3 987.7 1574.8 1202.8 1814.0 1634.5	277.6 288.9 319.4 350.6 497.8 523.9 534.9 907.6	53.0 58.8 62.1 62.4 58.9 62.5 69.5	5 6 7 28 17 2 2		75- 99-9 100-124-9 125-149-9 150-174-9 175-199-9 200-249-9 250-299-9 350-389-9 400-449-9	88.9 112.1 139.3 162.3 187.5 222.2 274.4 318.9 360.9	87.0 108.6 135.9 158.8 183.9 220.1 272.6 316.6 358.5 398.3	19.2 37.8 46.8 56.9 68.5 113.8 111.7 141.7 150.0	502.0 893.1 917.9 1029.5 1044.4 1175.5 1429.4 1175.5 1429.7 1060.7 1310.0	203.8 215.8 272.8 296.8 319.0 380.6 482.4 512.9 572.3 638.3	\$4.0 54.0 54.7 58.4 55.4 57.8 59.2 63.0 64.0	20 44 51 43 30 36 24 15
	25= 49.9 50= 74.9 75= 99.9 100=124.9 125=149.9	23.3 39.9 62.1 86.6 110.9 135.2	20.8 37.9 60.5 85.2 109.8 134.6	22.5 23.9 33.8 35.9 51.4 60.0	1567.0 1489.9 1572.8 1230.6 1321.0 1340.5	59+3 83.8 112.1 136.9 195.8 222.6	53.4 57.6 60.2 59.0 61.5	2 78 70 32 7 2	15	0- 24-9 25- 49-9 50- 74-9 75- 99-9 100-124-9	21.6 40.2 63.3 88.1 110.5	55.6 37.3 60.6 85.1 107.3	150.0 13.6 10.9 14.4 17.2 25.0	1310.0 491.4 549.0 580.3 481.7 599.8	638.3 131.3 98.9 144.7 193.9 224.6	39.1 43.2 47.6 48.7 52.6	278 412 680 504
5	25- 49.9 50- 74.9 75- 99.9 100-124.9	40.3 62.3 86.8 107.3	37-5 60-9 85-4 105-7	11.6 17.8 27.8 38.3	570.3 757.7 913.3 962.0	116.5 123.9 167.5 195.8	44-3 54-6 56-8 56-7	14 47 21 3		125-149.9 150-174.9 175-199.9 200-249.9 250-299.9	137.7 162.5 186.0 217.2 267.2	134.0 159.3 178.5 210.7 263.1	31.6 35.2 40.5 40.8 30.9	635.0 589.9 604.7 523.1 302.8	277.4 333.7 367.8 459.7 521.5	52.8 52.0 53.3 52.5 52.9	264 214 111 83 19
	25-49.9 50-74.9 75-99.9 100-124.9 125-149.9 150-174.9	14.7 42.9 66.3 87.1 107.6 137.5 159.0	40.9 64.2 85.1 106.2 135.9 158.0	14.3 21.6 22.3 20.8 27.4 41.1 30.0	1345.9 863.2 653.8 727.8 933.2 523.5	95.1 86.7 127.9 166.1 193.9 234.9 287.2	41.7 52.1 53.9 55.2 56.4 60.4 57.5	3 22 118 184 48 9	16	0- 24.9 25- 49.9 50- 74.9 75- 99.9 100-124.9 125-149.9 150-174.9	22.0 39.5 62.5 85.8 113.3 137.0 162.6 186.8	189.1 65.2 59.8 86.6 110.1 132.6 157.9 182.6	7.7 10.8 15.5 15.7 13.9 14.6 17.2	71.7 488.2 564.9 419.8 277.2 259.4 281.0	386.6 200.6 139.0 197.3 251.1 293.1 386.9 427.4 494.4	34.7 46.9 46.1 47.4 48.7 46.6 46.9	3 19 47 43 64 84 104
7	0-24.9 25-49.9 50-74.9 75-99.9 100-124.9 125-149.9 150-174.9 175-199.9	18.2 43.3 62.2 85.8 107.7 133.9 170.6 179.8	37.3 40.9 60.4 84.0 106.0 131.9 84.2 178.4	19.0 15.9 18.4 21.5 25.2 32.8 48.2 75.0	1084.8 911.1 769.9 684.3 663.4 781.6 797.2 1341.0	81.8 89.4 124.5 164.4 195.8 225.1 465.6 274.0	45.6 50.9 53.6 55.1 57.5 61.9 46.8 67.0	5 182 504 434 92 9	17	175-199.9 200-249.9 250-299.9 300-349.9 350-399.9 50-7449 75-99.9 100-124.9	226.3 271.3 317.7 370.9 65.8 93.4	222.0 267.0 313.6 367.2 60.0 90.8	16.2 15.7 20.2 21.4 12.5 29.1	236.0 182.7 131.4 124.4 100.1 538.5 770.8	427.4 494.4 697.4 781.8 960.3 125.0 199.0	48.0 47.4 43.8 40.4 54.0 50.8	139 105 30 7 2
8	200-2h9.9 25- k9.9 50- 74.9 75- 99.9 100-12h.9 125-1k9.9 175-17h.9 175-199.9 200-2k9.9 250-299.9 300-3k9.9	227.8 47.2 67.5 89.2 112.0 138.7 164.3 188.9 227.8 276.3 327.2	100.8 44.6 64.6 86.2 109.0 135.7 161.3 185.9 224.7 273.3 319.9	30.0 60.0 66.7 61.2 67.5 80.0 77.5 97.7 101.8 127.2	1140.0 1898.0 3190.0 2622.7 1627.5 1482.0 1269.2 862.5 1203.6 1078.8	84.1 102.5 128.4 205.5 312.4 445.0 417.7 492.0	74.0 57.0 66.0 63.0 56.2 54.3 58.0 48.5 58.2 58.2 58.3 60.2	1 2 3 4 4 8 4 13 20 23		125-149,9 150-174,9 175-199.9 200-249,9 250-299,9 300-349,9 350-399,9 400-449,9 450-499,9 5 500.0	115.2 137.3 162.6 186.3 224.3 274.4 323.9 373.2 426.5 472.0 535.2	110.1 132.7 158.1 180.6 219.6 269.5 319.6 366.0 421.3 467.0 496.3	30.6 32.2 42.4 53.8 66.8 73.9 90.6 110.8 111.1 113.5	745.9 638.6 682.6 682.6 867.7 825.9 765.2 813.2 886.5 772.0 630.3	226.2 268.8 325.8 362.9 432.7 517.0 611.2 680.6 829.8 962.9 989.4	54.2 53.6 53.9 54.6 55.6 55.8 57.4 54.6 53.1	96 171 125 111 212 174 181 67 40 20
9	350-399.9 h00-449.9 h50-899.9 ≥ 500.0 0- 24.9	369.9 422.4 471.1 549.9	366.9 408.5 468.2 533.8 22.5	135.0 163.6 182.8 225.0	1153.5 1275.5 1300.6 1346.2	619.0 659.7 709.0 861.2	58.8 64.3 64.3 64.8	25 33 29 36	18	150-174-9 175-199-9 200-249-9 250-299-9 300-349-9 350-399-9	173.9 191.0 221.0 271.0 329.6 402.5	168.0 183.9 217.6 268.2 326.6 398.5	15.0 33+3 21.4 36.1 112.5 100.0	120.0 175.0 197.6 331.0 1077.8 560.0	604.3 325.6 533.6 522.6 548.3 758.2	29.0 60.0 bl-3 53-7 61.8 54.0	1 3 14 9 4
10	25- 49.9 50- 74.9 75- 99.9 125-149.9 25- 49.9	40.1 59.1 77.8 125.4	36.6 56.3 74.6 123.6	10.9 8.8 10.6 15.0	652.6 357-7 263.0 150.0	86.7 133.8 203.2 313.3	49.8 48.3 40.8 41.0	131 46 5 1	19	25- 49.9 50- 74.9 75- 99.9 100-124.9 125-149.9	45.8 62.7 84.2	45.8 59.5 80.7 107.7 128.7	22.9 26.2 34.2 48.3 52.9	974.0 1084.6 1145.3 1191.4 1067.8	106.1 125.4 164.2 219.9 264.0	\$7.7 52.9 5\$.7 55.2	34 184 70 48
	50- 74.9 75- 99.9 100-124.9 125-149.9 150-174.9 175-190.9	60.8 87.8 111.9 136.7 161.8 186.0	59.5 85.6 109.5 133.9 154.2 183.1 211.3	23.9 14.5 52.6 60.2 65.7 81.7	1074.6 1530.3 1461.6 1356.8 1328.2 1565.4	110.7 149.3 178.7 224.9 266.5 289.3	58.0 64.2 63.8 61.7 60.4 64.9	169 79 39 26 21		150-174.9 175-199.9 200-249.9 250-299.9 300-349.9	137.0 161.3 187.5 213.7 285.0 327.2	128.7 156.6 178.3 207.2 279.0 323.0	52.9 60.4 77.7 68.7 48.3 112.5	1049.8 1245.3 1063.1 587.3 1093.5	300.0 311.8 359.1 484.1 540.1	55.3 56.8 62.5 61.2 61.0 61.5	13 48 26 21 3
	200-249.9 250-299.9 300-349.9 350-399.9	214-3 260-4 339-6 367-9	211.3 257.3 336.6 364.9	95.0 108.3 125.0 141.7	1712.6 1396.7 1308.0 1045.7	370.8 435.3 516.7 675.1	67.2 61.0 67.0 56.3	3 3	20	300-349.9 350-399.9 25-49.9 50-74.9	302.0 353.4 44.8 61.7	297.0 352.2 41.8 58.2	75.0 100.0 27.5 20.0	1223.5 928.0	781.8 712.4 93.4 110.0	40.0 51.0 49.0 57.0	2
1	0- 24.9 25- 49.9 50- 74.9 75- 99.9 100-124.9 125-149.9 150-174.9 175-199.9 200-249.9	18.5 41.1 59.1 82.0 107.8 132.0 163.5 179.7 216.6	13.8 37.6 56.8 79.2 104.9 84.9 81.6 176.0 196.8	9.5 11.3 15.2 21.4 23.5 37.5 41.2 50.0 149.4	1280.5 654.6 716.2 752.8 539.9 709.5 722.2 696.5 2091.4	57.7 87.4 110.9 150.8 216.7 243.9 262.6 390.2 350.6	34.0 50.0 55.5 56.2 52.3 55.8 64.0 47.5 63.5	746 583 57 10 4 4		50-74-9 75-99-9 100-124-9 125-149-9 150-174-9 175-199-9 200-249-9 250-299-9 300-349-9 300-349-9 450-499-9	61.7 83.6 112.6 133.5 162.4 187.1 226.0 274.8 326.3 3367.8 419.5 473.6	58.2 80.6 108.4 128.0 157.1 182.7 221.1 264.9 319.0 361.2 411.3 469.0	32.0 65.0 49.6 82.5 102.9 122.8 148.8 160.4 171.7 200.0	398.0 791.4 1481.2 845.6 1289.2 1342.1 1400.6 1440.0 1368.2 1316.7 1273.3	192.1 201.8 230.4 349.2 354.2 419.2 474.2 530.4 603.6 680.2 854.1	57.0 \$6.0 57.4 60.0 53.2 56.4 58.6 60.9 62.4 61.6 60.3 57.3	14 20 58 69 73 47 27
										≥ 500.0	543+3	537+3	225.0	1210.2	1007.8	58.4	8

An important question to farmers and agencies serving them is, "How do pumping plant characteristics vary in relation to changes in motor horsepower"? In order to answer this question, we grouped these 11,000 pump tests by nameplate horsepower, and retabulated them.

The tabulation includes six possible groups, according to horsepower, for each hydrographic area: 0-4.9, 5-14.9, 15-49.9, 50-99.9, 100-249.9, and equal to, or greater than 250 horsepower. We note here that a case can be made for using input rather than plate horsepower in such tabulations, because the former indicates actual power input. Motors can vary in actual load within certain limits (see Table 4).

TABLE 4

Wean Pumping Flant Characteristics by Hydrographic Area and Flate Horsepower San Joaquin Valley, 1949-54

interval in H.P. 1 0- 4.9 5- 14.9 15- 49.9 50- 249.9 100-249.9 0- 4.9 5- 14.9 15- 49.9	2.0 9.2 22.8 57.4 100.0	Pump depth 3 15.1 37.0 47.2	Total lift 4	G.P.M.	K.W.H. per acre-foot	plant efficiency	of tests	11	interval	Horse-	Pump	Total		K.W.H. per		of
0- 4.9 5- 14.9 15- 49.9 50- 99.9 100-249.9 0- 4.9 5- 14.9	2.0 9.2 22.8 57.4	37.0	15.1	. 5	6			Area	in H.P.	power	depth		G-P-M-	acre-foot	efficiency	tests
5- 14.9 15- 49.9 50- 99.9 100-249.9 0- 4.9 5- 14.9	9.2 22.8 57.4	37.0		1		7	- 8		1	2	3	14	5	6	7	- 8
0= 4.9 5= 14.9		72.9	39.8 48.9 75.1 118.2	120.0 588.8 1213.7 2120.5 2245.0	139.0 86.8 92.0 125.9 190.0	11.0 47.7 53.7 60.5 63.5	1 30 161 19	12	0- 4.9 5- 14.9 15- 49.9 100-249.9	2.9 8.1 18.2 220.0	60.6 73.3 75.9 62.1	64.5 78.0 82.4 66.5	99.5 256.4 635.5 337.0	312.2 197.1 179.5 119.0	29.6 44.6 48.9 57.0	10 351 152 1
	3.0 5.0 34.3	23.8 52.4 77.8	29.2 52.4 80.0	47.0 243.0 1234.3	354.0 99.0 154.6	9.5 54.0 55.2	2 1 29	13	15- 49.9 50- 99.9 100-249.9 > 250.0	35.0 61.7 152.9 272.8	204.8 242.1 401.9 566.4	207.8 244.8 404.8 569.8	449.5 759.0 1191.5	200.2 149.9 660.6	57.0 57.7 60.8	2 27 165 68
50= 99.9 100=249.9	68.1	140.5 192.6	142.7	1288.1	265.7 368.8	57.7 54.2	27 24	14	5- 14.9	8.7	90.7	92.4	259.4	250.0	42.8	13
5- 14.9 15- 49.9 50- 99.9	9.6 28.2 59.4	37.1 72.4 155.1	74.8	1178.0	114.5 139.5 276.8	44.4 56.4 58.0	5 84 32		50= 99.9 100=249.9	63.2 141.8	175.5 245.9	179.0 248.3	1055.8 1719.2	316.0 416.6	57.4 59.4	94 67
≥ 250.0	250.0	534-7	536.8	1407.0	907.6	61.2	4	15	5- 14.9	8.3	77.9	81.2	270.4	198.9	44.1	760 1,561
5- 14.9 15- 49.9 50- 99.9	8.9 27.2 54.7	35+3 53+6 82+6	38.5 55.3 84.1	554.9 1417.1 2009.9	81.4 104.7 143.5	49.4 55.9 60.0	11 147 33		50= 99.9 100=249.9	56.3 105.4	157.7	160.8 164.9	1019.3 1991.5	296.3 269.7	57.9 63.1	234 14
5- 14.9 15- 49.9 50- 99.9	9.0 20.5 55.0	51.5 67.7 84.2	53.7 69.2 85.9	395.1 805.2 1845.5	133.8 136.6 138.1	46.5 55.1 64.3	22 57 6	16	0= 4.9 5= 14.9 15= 49.9 50= 99.9	3.0 8.7 19.8 50.0	162.0	162.9 189.1	45.0 151.8 300.0 715.0	326.7 406.8 434.7 339.4	15.0 46.5 47.2 57.3	261 459 6
5- 14.9 15- 49.9 50- 99.9	9.3 21.9 60.3	74.6 80.0 90.4	76.2 81.8 92.0	273.6 771.0 1708.6	181.4 152.2 157.7	44.5 55.6 59.0	34 334 18	17	5- 14.9 15- 49.9 50- 99.9 100-249.9	10.4 28.1 63.6 122.0	122.3 168.8 236.1 310.5	129.6 173.2 240.6 318.7	264.0 463.8 837.0 1183.9	316.8 354.2 454.2 584.0	47.6 52.4 56.3 56.9	24 485 389 290
5- 14.9	2.8 8.8	57.7 56.7	81.8 58.8	58.6 386.9	323.4 131.0	25.6 48.2	270 270		> 250.0	250.0	344.8	348.3	2556.8	550.4	65.0	4
50- 99-9	60.3	82.2 91.0	91.5	1826.2	150.8	61.7 57.2	34	18	15= 49.9 50= 99.9	25.0 64.2	225.7 247.9	229.3 250.7	261.1 970.2	499.6 460.7	48.0 57.3	3 22 6 3
15- 49.9 50- 99.9 100-249.9	31.7 66.1 146.8	169.6 175.1 381.6	172.5 181.3 390.3	1305.7 1339.9 1213.0	293.2 331.9 637.0	60.0 57.5 61.6	3 31 147	19	5- 14.9	9.1	70.2	75.0	339.0	179.1	46.1	47 284
> 250.0	270.8	525.2	528.1	1682.0	813.5	64.8	24		50= 49.9 50= 99.9 100=249.9	64.3	129.2	134.3	1548.2	233.4	59.9 59.0	140
0- 4.9 5- 14.9 15- 49.9	3.0 8.0 15.8	39.9 42.8 43.7	43.7 46.4 46.1	109.5 411.5 915.2	151.0 106.6 90.5	51.7 47.6 53.6	119 59	20	50= 99.9 100=249.9	75.0	297.0 352.2	302.0 353.4	484.0 737.0	781.8 712.4	40.0 51.0	1
5= 14.9 15= 49.9 50= 99.9 100=249.9	8.7 26.4 61.5 112.0	52.3 70.3 115.1 216.8	57.2 71.8 117.8 219.8	434.7 1089.4 1671.9 1831.5	102.8 125.3 200.8 363.0	51.1 59.6 63.4 64.2	27 235 104 25	21	5- 14.9 15- 49.9 50- 99.9 100-249.9	9.0 26.3 65.7 148.6	129.5 170.3 236.0 305.9	179.0 174.8 240.8 313.3	133.0 459.2 919.1 1499.8	305.4 415.2 404.8 529.0	55.5 48.5 60.3 61.0	2 30 45 249
0- 4.9 5- 14.9 15- 49.9 50- 99.9 100-249.9	3.0 8.8 18.4 67.5 152.8	27.1 43.2 53.6 68.7 192.4	29.9 46.6 56.9 104.1 194.5	180.3 476.8 922.0 1033.9 2465.6	86.8 98.5 105.9 171.0 322.4	35•3 49•9 55•7 56•8 60•9	3 758 640 10 9		⋝ 250.0	254.5	463.5	467.6	1896.6	737-2	65.3	11
	5-1k.9 15-49.9 100-289.9 5-250.0 5-1k.9 15-49.9 5-1k.9 15-49.9 5-1k.9 15-49.9 5-1k.9 15-49.9 5-1k.9 15-49.9 5-1k.9 15-49.9 5-1k.9 15-49.9 5-1k.9 15-49.9 5-1k.9 15-49.9 5-1k.9 15-49.9 5-1k.9 15-49.9 5-1k.9 15-49.9 15-49.9 15-49.9 15-49.9 15-49.9 16-24	5-11.9 9.6 1.1 1.1 1.1 1.1 1.1 1.1 1.1 1.1 1.1 1	5 14.9 8.6 371.1 5 24.9 8.6 371.1 5 25.0 8.6 371.1 5 25.0 8.0 8.0 1.0 5 25.0 1.0 1.0 1.0 1.0 5 25.0 1.0 1.0 1.0 1.0 5 25.0 1.0 1.0 1.0 1.0 5 25.0 1.0 1.0 1.0 1.0 5 25.0 1.0 1.0 1.0 1.0 1.0 5 25.0 1.0 1.0 1.0 1.0 1.0 5 25.0 1.0 1.0 1.0 1.0 1.0 5 25.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1	5-11-9	5 14.9 9.6 37.1 38.3 897.6 70.0 9.0 9.0 9.1 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1	5-11-9 8.6 37.1 38.1 897.6 114.5 150-89.6 19.1 19.1 19.1 19.1 19.1 19.1 19.1 1	5-14-9 9.66 37:1 38.3 897:6 114.5 5 44.4 1.4 1.4 1.4 1.4 1.4 1.4 1.4 1.4 1.	5-14.9 9.6 37.1 38.3 897.6 113.5 44.4 5 1.0-99.9 29.4 174.1 78.3 1107.0 129.5 56.4 63.4 12.0 129.5 29.4 174.3 1107.0 129.5 129.4 174.3 1107.0 129.5 129.4 174.3 1107.0 129.5 129.4 174.3 1107.0 129.5 129.4 174.3 1107.0 129.5 129.4 174.3 129.5 129.4 174.3 129.5 129.4 129.4 129.5	5-11-9 9.66 37:1 38:3 897:5 113:5 5 43.4 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	5-1k-9 9.66 37.1 38.3 897.6 11k-5 1k-4 5 5 50-99.9 12-10-0-0-0-9.9 28.4 12-1 17-16 114-73 139.5 56.4 12-1 17-16 114-73 139.5 56.0 92 100-0-0-0-9.9 28.4 12-1 17-16 114-73 139.5 56.0 92 100-0-0-0-9.9 28.4 12-1 17-16 114-73 139.5 56.0 92 100-0-0-0-9.9 28.4 12-1 17-16 114-73 139.5 56.0 92 100-0-0-0-9.9 28.4 12-1 17-16 114-73 139.5 14-74 11-10-0-0-0-0-9.9 12-10-0-0-0-0-9.9 12-10-0-0-0-0-9.9 12-10-0-0-0-0-9.9 12-10-0-0-0-0-9.9 12-10-0-0-0-0-9.9 12-10-0-0-0-0-9.9 12-10-0-0-0-0-9.9 12-10-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-	5 - 14.9 9.6 37.1 38.3 897.6 114.5 144.4 5 5 29.9 99.6 37.1 38.3 897.6 114.5 144.4 5 5 29.9 99.6 141.8 126.7 144.8 126.7 145.5 145.5 145.4 141.5 100.000, 10	5 - 14.9 9.6 37.1 36.3 897.6 114.5 5 44.4 5 5 20.09.9 26.3 277.5 27.5 27.5 29.2 29.7 29.8 29.9 29.4 12.1 136.6 1167.3 139.2 56.4 56.4 12.1 15.0 20.09.9 13.8 29.1 136.6 1167.3 139.2 56.4 56.4 12.1 15.0 20.09.9 13.8 29.1 136.6 1167.0 907.6 61.2 4 1.5 5 2.4 9.9 14.7 20.0 29.0 12.1 136.6 1167.0 907.6 61.2 4 1.5 5 2.4 9.9 12.1 136.6 1167.0 907.6 61.2 4 1.5 5 2.4 9.9 12.1 13.5 29.9 13.7 13.8 13.8 14.7 14.7 59.9 14.7 100.249.9 13.9 13.9 13.8 14.7 13.8 14.8 14.7 13.8 14.8 14.8 14.8 14.8 14.8 14.8 14.8 14	5 - 14.9 9.6 37.1 38.3 897.6 114.5 144.4 5 92.9 99.9 14.5 15.2 175.5 175.0 175	5 - 14.9 9.6 37.1 36.3 897.6 114.5 44.4 5 5 20.0 29.0 19.4 19.1 19.1 19.1 19.1 19.1 19.1 19.1	5 - 14.9 9.6 37.1 38.3 897.6 114.5 44.4 5 6 90.99.9 125.1 37.1 38.3 897.6 114.5 44.4 5 6 90.99.9 25.4 174.1 78.6 1167.3 135.6 35.4 56.4 6 90.00-69.9 114.1 69.9 28.5 117.9 115.5 136.0 100-69.9 114.1 69.9 28.5 117.9 115.5 136.0 11	5-14.9 9.6 37.1 38.3 897.6 131.5 14.4 5 5 90-99.9 89.2 127.2 130.2 622.7 897.1 55.3 10.0-89.9 13.4 17.1 130.3 135.8 86.2 89.9 10.0-89.9 13.8 89.1 18.1 19.5 19.9 10.0-89.9 13.8 89.1 18.1 19.5 19.9 10.0-89.9 13.8 18.5 19.1 19.1 19.1 19.1 19.1 19.1 19.1 19

Irrigation Wells

The California State Water Code, Sections 7076, 7077, and 7078 requires anyone who drills a new well, deepens an existing one, or reconditions or abandons a water well, to report the work accomplished to the appropriate Regional Water Pollution Control Board. These reports include information on location, proposed use, equipment used, casing installed (including diameter, gauge and depth), extent of gravel pack, perforations in casing wall, water levels, results of pump tests, and a log of the formations and material encountered in drilling. This law has only been in effect since 1949; compliance, furthermore, has been far from complete. Thus, the number of reports available is small, relative to numbers of wells in operation.

We obtained 584 usable reports from Regional Water Pollution Control Board Number 5, which includes the San Joaquin Valley. Not only was this sample small in size, but individual reports were incomplete in certain categories of information.

These 584 reports, however, represent the best information available on the subject; in spite of their admitted limitations they proved to be very helpful.

We present in Table 5 mean values for well characteristics for each hydrographic area for which data were available, as calculated from these reports.

Pump Operating Characteristics

Many bulletins, circulars, and pamphlets are available on selecting, operating and using irrigation pumps. This section includes a limited selection of such information to illustrate how changes in certain operating characteristics can affect the cost of pumping water.

Farmers in the San Joaquin Valley operate a wide range of pumps and motors to meet the varying conditions under which they pump irrigation water. A farmer's first step in selecting a pump is to examine pump performance curves available from pump manufacturers (see Figure 3). The pump in Figure 3 attains its maximum

TABLE 5

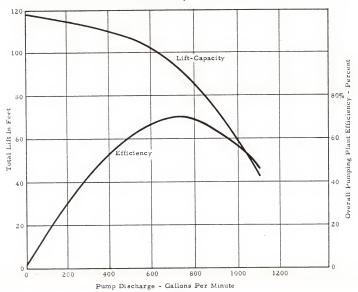
Mean Irrigation Well Characteristics by Hydrographic Area, San Joaquin Valley, 1950-60

		Type o	of rig	Type o	essing	Casi thic		Casin diame	ter	Casing	depth	Gravel :	packed	Gravel p	acked	Casin perfo	rations	Total devel	well opment
Area number	Total number of reports	Rotary 2	Cable	Single casing	Double casing	report-	Thick- ness (in.)	Number report- ing	Top diam- eter (in.)	Number report- ing	Depth (ft.)	Number report- ing	Diam- eter (in.)	Number report- ing	Depth (ft.)	Number report- ing	Depth perfora- tion (ft;)	Number report- ing	Depth
	1		-3-			-		-	-	10	-11	12	13	14	12	10			
3	7	3	4	7	0	7	.214	7	18	7	171	7	30	2	1,116	. 7	154	6	50
7	41	6	35	41	0	40	.140	41	13	41	188	6	22	6	253	23	112	37	22
8	3	3	0	3	0	3	.312	3	16	3	722	0	0	0	0	3	342	3	1,01
10	47	19	27	40	7	41	.153	46	14	47	250	21	23	23	262	33	148	47	26
11	193	74	119	187	5	188	.119	191	12	193	154	34	21	32	184	88	112	193	18
12	29	2	27	28	0	28	.110	28	12	28	126	0	0	0	0	17	71	29	15
13	6	6	0	6	0	6	.236	6	14	6	624	5	25	4	959	5	548	6	1,04
14	28	22	6	27	0	28	.219	28	15	28	614	20	25	8	577	20	324	26	678
15	68	26	41	66	0	66	.158	66	13	66	408	15	31	7	666	30	196	65	41
17	44	36	8	144	0	1414	.234	43	14	l ₂ l ₄	1,000	32	24	23	1,172	35	529	44	1,019
19	94	69	25	91	0 -	92	.225	93	15	93	453	67	25	46	513	92	277	89	47
20	6	6	0	6	0	6	.270	6	15	6	821	4	28	1	1,476	4	625	4	1,25
21	18	13	5	17	0	18	.235	18	19	18	805	10	26	9	888	17	495	17	84

Source: California Regional Water Control Board Rumber 5; calculations by the authors.

Figure 3

Pumping Plant Performance For Typical Deep Well
Turbine Pump



Source: Pump manufacturer's data.

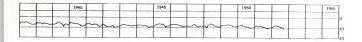
discharge (g.p.m.) at a total lift (lift-capacity) of about 40 feet; maximum plant efficiency accompanies a discharge of about 700 g.p.m. If a farmer selects a pump for a well with an initial total lift of 50 feet, only to find a falling water table, two things will happen; first, pump discharge will decrease; second, plant efficiency will increase until the discharge falls below 700 g.p.m., then it also will decrease. It happens quite frequently that water tables fall in the southern San Joaquin Valley. Such occurrences may be due to seasonal drawdown or to an overdraft of the ground water basin. Regardless of cause, a drop in water table, such as in the example cited, may mean increased costs for the operator. According to the formula for computing kilowatt-hours per acre foot of water, this effect will depend on the relative slopes of the two curves for head-capacity and efficiency (KWH/acre-foot = 1.024 . total lift power bill may increase, decrease, or remain constant when the water table falls. Sharp declines usually will bring higher pumping costs, and may mean that the plant will be unable to furnish enough water for irrigating the crops that it is supposed to serve. Such declines can be serious enough that the well ceases to produce any appreciable quantity of water, and therefore, the farmer must deepen it, and change horsepower and other plant characteristics, or make other arrangements to obtain the water necessary for his operation.

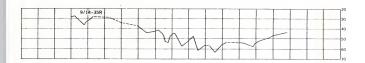
Seasonal Drawdown in Wells

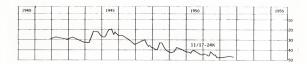
In almost all parts of the San Joaquin Valley pumping lifts are smallest early in the year immediately after winter rains and the melting snow packs have recharged the aquifers. Total lifts then increase as pumping continues during the summer irrigation season and reach their maxima in the late summer and fall. Well hydrographs for various locations in the Valley, obtained from the U. S. Bureau of Reclamation, show this typical pattern (see Figure 4).

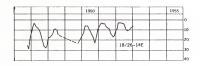
Rainfall is light in Westside, and stream runoffs supply only small amounts of recharge. Quantities pumped here are greater than annual recharge. The

A. TYPICAL WELL HYDROGRAPHS NORTHERN & EASTERN SAN JOAQUIN VALLEY

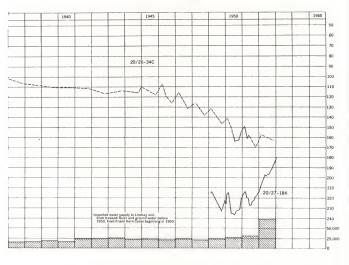


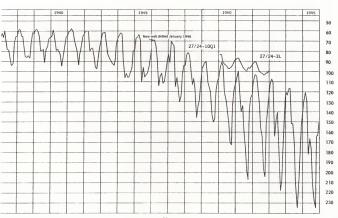




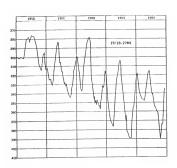


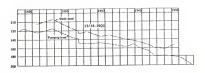
B. TYPICAL WELL HYDROGRAPH SAN JOAQUIN VALLEY EASTSIDE





C. TYPICAL WELL HYDROGRAPHS SAN JOAQUIN VALLEY WESTSIDE





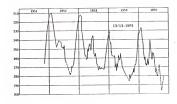
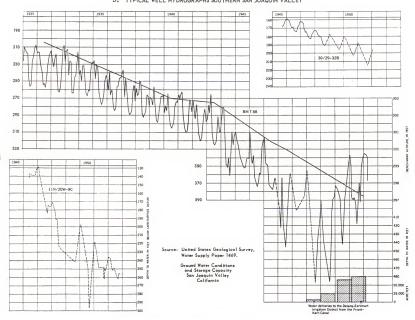


FIGURE 4

D. TYPICAL WELL HYDROGRAPHS SOUTHERN SAN JOAQUIN VALLEY



resulting ground water overdraft causes average total lift to increase year after year, and forces farmers periodically to deepen wells, increase motor horsepower, and increase the number of pump stages. All of these capital improvements are expensive (see Figure 4-c).

Typical Power Costs for Pumping Irrigation Water

It is useful in this analysis to compute typical power costs for pumping irrigation water in the several hydrographic areas of the San Joaquin Valley. Total pumping lift is the most important physical factor governing kilowatt-hours and power costs per acre-foot of water. We selected values for mean pump characteristics in modal class intervals (those with the greatest number of tests) to represent a typical pumping plant in each of the 21 hydrographic areas (see Table 3). Our first assumption in using these data is that these physical characteristics (total lift, discharge, and efficiency) represent midseason conditions with respect to seasonal drawdown. We then estimated total energy cost by calculating kilowatt-hours and outlays for one-fourth of the water under spring, one-half under midseason, and one-fourth under late summer and fall conditions. Some of the hydrographic areas with very similar pumping characteristics are combined in these calculations.

Assumed total lifts, discharges in g.p.m. and plant efficiencies for these three pumping periods appear in Table 6. We estimated these seasonal values for the three pumping periods by fitting pump performance curves to the typical pump characteristics for each area. Fump dealers and manufacturers' representatives furnished valuable counsel and aid in preparing these estimates, which then served us as the basis for estimating costs of pump and motor components. We recognize that our estimates have obvious limitations, based on the kinds of data available and the methods that were applicable in preparing them. We suggest, in spite of these faults, that these estimates according to hydrographic areas are useful.

TABLE 6
Assumed Pump Characteristics for Three Pumping Periods by Rydrographic Area, San Joaquin Valley

I		h lift pe			m lift pe	riod	Low	lift per	iod
	Total		Plant	Total		Plant	Total		Plant
Area	lift	G.P.M.	eff.	lift	G.P.M.	eff.	lift	G.P.M.	eff.
	1	2	(%)	4	5	6	7	8	9
	(ft.)		(%)	(ft.)		(%)	(ft.)		(%)
1 & 4	44.8	1,194	50.4	39.8	1,344	52.4	34.8	1,495	54.4
9 & 11	45.9	404	46.0	40.9	654	50.0	35.9	904	54.0
10	65.8	975	56.0	60.8	1,074	58.0	55.8	1,175	60.0
19	72.7	884	48.9	62.7	1,085	52.9	52.7	1,285	56.9
2 & 3	67.3	1,336	56.5	62.3	1,487	60.5	57.3	1,637	64.5
7	64.2	730	52.6	62.2	769	53.6	60.2	810	54.6
5	64.3 89.1	718 614	53.6	62.3	758	54.6	60.3	978	55.6
12	87.2	246	51.2 44.8	87.1 87.2	654	55.2	85.1	694	59.2
15	93.1	382	45.7	88.1	246 482	44.8	87.2	246	44.8
17	147.3	528	48.6	137.3	639		83.1	582	51.7
14	144.3	863	52.7	139.3	918	53.6	127.3	749	58.6
16	167.6	181	44.6	162.6	241	46.6	157.6	983	56.7 48.6
18				105.0	241	40.0	151.0	301	40.0
20 & 21	340.9	1,127	50.0	325.9	1,427	62.0	310.9	1,727	74.0
8 & 13	439.3	921	49.9	424.3	1,221	61.9	409.3	1,521	73.9
	.57.5	/	.,,,,	12.00	,	01.9	409.3	1,721	13.9

Source: Calculated by the authors from pumping plant and well characteristics and engineering data.

In the absence of more precise information, they provide an over-all perspective on the factors affecting power costs for pumping irrigation water in the San Joaquin Valley. They also indicate some of the major variations among these hydrographic areas.

Repair and Maintenance Costs

Neither accurate records nor comprehensive sample data on pump repair and maintenance costs for the San Joaquin Valley were available for this analysis. One of the larger farming companies in the Valley, however, did furnish detailed records on repair and maintenance costs for a five-year period including more than 400 pumps. These pumps, scattered over a wide geographic area, represent three distinct ground water conditions. Total pump lifts under condition Number 1 are less than 100 feet, while the water table is fairly stable and subject to little or no ground water overdraft. Condition Number 2 represents conditions with total pump lift about 160 feet, and the water table falling at a rate of 3-4 feet per year. Condition Number 3 has the most extreme conditions; total lift is about 350 feet and the water table is falling at a rate of 8-10 feet per year.

The repair costs presented here also have their limitations. Again, however, we believe that they are sufficiently representative to justify using them in preparing estimates for other parts of the Valley. We obtained such estimates by expressing repairs and maintenance costs as percentage of original outlays for the pumps and motors in the several hydrographic areas (see Table 7).

Well Drilling Costs

Well drilling charges, and the methods used to determine them vary widely among areas. The most important cost-regulating factors include well depth, type of material drilled through, casing diameter and thickness, and amount of gravel packing.

A survey of well drillers in the San Joaquin Valley revealed a wide range in charges among the various areas (see Table 8).

TABLE 7

Irrigation Pump and Well Repairs and Maintenance Costs for Three Ground Water Conditions, San Joaquin Valley

Area No. 1 Area No. 2 Area No. 3 Percent Percent Percent of total of total Item Cost Cost Cost of total 7 2 3 5 6 Repairs: a/ 22.72 14.7 57.60 12.8 Motor 6.56 Electrical 4.3 23.68 5.2 Column, tube, and shaft .48 17.28 3.8 6.2 Well 9.60 7.36 1.6 1.12 3.5 Pump head 1.8 6.40 Unclassified 2.72 1.4 Subtotal 43.20 128.16 28.4 402.08 28.0 Costs incurred due to increased pump lift: Pump bowl changes 44.80 29.0 115.36 25.5 56.16 36.4 Horsepower increases 201.76 44.7 6.40 Other capital increases 10.08 6.5 7.4 111.04 Subtotal 323.52 71.6 1,033.92 72.0 154.24 TOTAL 100.0 451.68 100.0 1,436.00 100.0

a/ Costs not broken down.

Source: Calculated by the authors from pumping plant characteristics and engineering data.

TABLE 8

Typical Well Drilling Charges per Foot of Depth in the San Joaquin Valley, a/ (taxes not included)

Casing	size	Drill	ing	
Top		Without	With	Perforating
diameter	Thick-	gravel	gravel	the
(inches)	ness	envelope	envelope	casing
	1.	2	3	- 4
	gauge		dollars	
12 14 14 16 16 18	10 10 8 10 8	5.25 6.25 7.40 7.25 8.40 9.40	6.75 8.75 10.00 10.75 12.00 14.00	1.66 1.94 2.44 2.21 2.79 3.13

a/ Well development by pumping; average of \$200 - \$350 for shallow wells, \$1,000 for wells exceeding 1,000 feet in depth.

Source: Data obtained by interviews with well drillers.

Average Total Pumping Costs

Annual fixed costs are those that do not vary with the amounts of water pumped. In this analysis, fixed costs include two noncash and three cash items: depreciation, interest on investment, capital improvements, taxes, and demend charges. Annual depreciation is the yearly cost for consuming the capital investment. We obtained this item by dividing original cost, less any salvage value, by the estimated life for the pump or well in years. The assumption in this study is that 40 percent of the original motor cost represents the salvage value for the entire pumping plant.

Pump dealers, farmers, and others with knowledge of conditions in the areas, furnished information on length of life for the wells and pumps. These are difficult values to estimate for many of the areas, especially for the Westside and the southern tip of the Valley. Very few wells in these areas have existed for as long a period of time as that estimated to be the average length of life. Interest on investment is a noncash cost for using the average capital invested in the facilities, calculated at six percent per annum in this study.

Capital improvement costs appearing in Table 7 include fixed costs, due to declining water tables. Among the specific requirements necessitating such added capital are increased horsepower, additional stages for the pump, and longer columns, tubes, and shafts essential to maintain pump discharges at greater pumping depths. We list these under fixed costs because an individual pump can exert little or no affect upon the ground water levels in large basins such as those in the Sen Joaquin Velley. Operators, however, must make the expenditures involved in order to use the plants. Taxes represent a cash overhead cost, levied by county and local authorities on the assessed value of property.

The service or demand charge for the pump also is a cash outlay, charged by power companies. These are annual costs varying with motor horsepower, and not

according to hours of operation (see Appendix Table 1 for schedule). Power companies levy the demand charge if the motor is connected to their lines. It can be avoided only by disconnecting the unit. We have assumed that the farms in this study are going concerns, and therefore, that these charge represent fixed costs.

Variable expenses include all required outlays that vary with the quantity of water pumped. Easiest of these to determine is the pumping power or energy charge; it is based upon the number of kilowatt-hours used by the motor, and is determined by applying power company rates shown in the Appendix. Our estimates in this study reflect the three assumed seasonal pumping conditions. We obtained the total energy charge on the further assumption that a pump can serve one acre for each 9 g.p.m. of discharge at midseason, and that the full season's irrigation requires 36 inches of water per acre.

We distributed our estimated total annual repair and maintenance costs over the total quantities of water pumped during the season. The sums of these fixed and variable costs represent total estimated costs for pumping irrigation water in the various San Joaquin Valley hydrographic areas (see Table 9).

Surface Water Supplies

Most San Joaquin Valley operators on irrigated farms depend on surface water sources to supplement ground water supplies. These supplemental quantities become most critical during drought periods. Prolonged droughts, extending through two or more years, cause recharges of underground besin to be less than normal. These reductions, in turn, lead to pumping overdrafts and increased lifts. Surface supplies also are shortest during such periods, due to reduced stream runoffs.

It is practically impossible to generalize about surface irrigation water supplies in the San Joaquin Valley. This is due to the statutory and regulatory framework governing California water allocations, and to the number and types of organizations distributing water to farmers.

TABLE 9

Investment in Wells and Pumping Plants and Oosts of Pumping Water by Hydrographic Area, San Josquin Walley

Area	Well cost l	Est. well life 2 years	Pump cost 3	Est. pump life 4	Total annual depreci- ationa	Interest and tax	Cost due to lower water table	Service demand charge 8	Total fixed cost	Repair and mainte- nance	Energy charge	Quantity pumped 12	Fixed cost per ac. ft.	Variable cost per ac. ft.	Total cost per ac. ft.
1 & 4 9 & 11 10 19 2 & 3 7 5 6 12 15 17 14 16 18 20 & 21 8 & 13	2,301 1,406 2,600 7,044 8,122 2,002 2,002 2,002 1,177 2,836 12,980 9,766 2,836 15,007 14,000	20 20 20 15 20 20 20 20 20 20 20 20 20 20 20 20 20	2,790 1,860 2,598 2,598 3,545 2,580 2,580 2,891 4,422 4,769 3,179	20 20 20 20 20 20 20 20 20 20 20 20 20 2	242.85 140.89 217.55 563.15 483.38 197.38 212.73 146.73 246.29 721.55 864.22 260.69 1,731.77 2,013.33	204.89 138.80 220.92 409.78 495.85 194.74 194.74 207.78 141.82 243.40 617.74 255.64 1,326.55 1,347.25	0 74.40 103.92 103.92 0 0 0 0 309.54 333.83 0 	134-60 74-60 168-25 168-25 201-90 134-60 134-60 134-60 134-60 201-90 299-50 134-60 789-00 789-00	582.34 428.69 710.64 1,265.10 1,181.13 526.72 526.72 525.11 463.15 624.29 1,97.57 2,115.29 650.93 4,981.74 5,388.58	55.80 37.20 51.96 51.96 70.90 51.60 51.60 57.74 43.20 57.82 132.66 143.07 95.37 486.18 531.00	439.40 135.65 495.50 547.82 625.02 393.48 384.66 437.38 130.25 387.51 686.32 962.14 377.84 3,016.78 3,288.32	8c. ft. 449.7 218.1 358.2 361.5 495.6 265.5 252.6 217.8 82.2 160.5 213.0 306.0 80.4 475.8 406.8	1.29 1.97 1.98 3.50 2.38 1.98 2.55 5.63 3.89 9.25 6.91 8.10	dollars 1.10 .79 1.53 1.66 1.68 1.73 2.27 2.11 2.77 2.11 5.89 7.36	2.39 2.76 3.51 5.16 3.68 3.68 3.68 7.74 6.66 13.09 10.52 13.99 17.83 22.64

- a/ Salvage value of 40 percent of pump cost was credited to pump unit.
- b/ Four percent of new pump cost for areas 9 & 11, 10 & 19; 7 percent for areas 17, 14, 20 & 21, and 8 & 13.
- c/ Thirty-six acre inches per acre of summer crops. This will understate the amount pumped in areas where winter crops are irrigated and will cause the cost per acre foot to be overstated for these same areas.
- d/ Insufficient information.

Source: Calculated by authors from pumping plant and well characteristics and engineering data.

Riparian rights to stream flow are important to contiguous land holders, but only a small portion of Valley land is eligible for water under the Riparian doctrine. Appropriative rights are the most important basis for obtaining water in terms of land area, but the supply of water available to an individual grower under this doctrine depends upon circumstances affecting the specific case.

Either individuals or organizations may hold appropriative rights. Individuals, furthermore, may assign their rights to an organization, or retain them and arrange for an organization created for this purpose to deliver water to them. The rules governing appropriative rights specify the time, place, and quantities that the holder may divert. Regulations concerning time also specify the minimum flow that must be in the stream before the appropriative right holder may divert, and the times of the year he may divert this water.

Organizations distributing water may obtain their water supplies from more than one source. An irrigation district, for example, may divert water from a stream, have a contract with the Bureau of Reclamation to obtain water from an interriver basin aqueduct, and also pump from its own underground wells.

Irrigation water delivery can occur under one or more of several methods. The most obvious, and a very important method, is to conduct water through canals or pipelines to farm headgates. The second method, also important and widely used, is to use the water in recharging underground basins artificially. Several procedures are available for accomplishing such deliveries; spreading water through especially constructed beds or fields, pumping it down abandoned well shafts, or feeding it into unlined canals and ditches during the off-season for irrigation. In each instance, water percolates downward to accumulate in underground storage, later being pumped by individual farmers as they need it.

Wide year-to-year variations characterize irrigation water supplies available for distribution by many irrigation districts, and other agencies. A district with a senior appropriative right, for example, will have fairly reliable water supplies except during the driest years. Another district, or mutual water company, with c

junior appropriative right may receive water only during high precipitation years, or during high stream flow seasons. Farmers in certain parts of the San Joaquin Valley have filed claims for flood waters that cannot be expected more than once in 20 years.

Year-to-year fluctuations in irrigation water supplies can be reduced by conservation storage dams. Such structures enable the water agency to carry over to the following or later years the excess runoff in a wet year. Some irrigation districts have constructed their own storage dams; others have entered into agreements with governmental agencies for storage capacity behind multiple-purpose dams. Very little research has been done to determine optimum carry-over policies for irrigation water storage.

Runoff within any given year varies widely emong stremas, although there is a tendency for streams in the same general region to vary in the same direction. Streams with large watersheds in the high mountain areas of the Sierra Nevadas have less variation in runoff, however, then those streams with watersheds in the foothills and low elevations (see Table 10 for major stream flows entering the San Joaquin Valley 1950-1960).

Actual farm headgate deliveries by irrigation districts do not always vary directly with stream runoff. Conservation storage, the nature of the rights held by the district, the possibility that water is imported from other watersheds by the Bureau of Reclamation, all may affect such deliveries. Those responsible for water spreading and other methods of recharge also may modify the influence of stream flows by curtailing recharge during dry years; instead, delivering the water directly to farms.

We have listed the sources of supply, and water supplied per irrigated acre for selected irrigation districts in the San Joaquin Valley for eight years (see Table 11).

TABLE 10

Seasonal Flow for Major Streams in the San Joaquin Valley as Percent of Normal, 1950-51 to 1959-60

					Year					
Stream	1959 - 1960	1958 - 1959	1957 - 1958	1956 - 1957	1955 - 1956	1954-	1953-	1952-	1951-	1950-
Darcean	1	2	3	4	5	1955	1954	1953 8	1952 9	1951
					percent					
San Joaquin Kaweah Tule Kern Kings Stanislaus Toulumne Merced	47 44 28 41 43 51 57 49	64 49 40 76 60 49 54	119 126 149 113 127 107 115	76 73 53 63 75 65 65 52	173 176 169 103 141 162 178 172	66 68 49 54 68 59 61 54	72 75 76 72 75 77 78 68	67 75 83 84 69 83 83	173 203 263 235 170 165 165	105 103 68 90 97 146 134 124

Source: Water Conditions Report, California Department of Water Resources.

TABLE 11 Surface Irrigation Water Supply by Irrigation District, 1951-58

			1958			1957			1956			1955 a/			1954			1953			1952			1951	
		Total		Acre	Total		Acre	Total		Acre	Total		Acre	Total		Acre	Total		Acre	Total		Acre	Total		TA
		deliv.	Irri-	feet	deliv.	Irri-	feet	deliv.	Irri-	feet	deliv.	Irri-	feet	deliv.	Irri-	feet	deliv.	Irri-	feet	deliv.	Irri-	feet	deliv.	Irri-	1 :
		(acre	gated	per	(scre	gated	per	(acre	gated	per	(acre	gated	per	(acre	gated	per	(acre	gated	per	(acre	gated	per	(sore	gested	11
District	Source	feet)	acres	acro	feet)	acres	sere	feet)	acres	ecre	feet)	sores '	acre	feet)	seres	acre	feet)	acres	acre	feet)	acros	acre	feet)	sores	
		1	2	3	4		- 6	7	8	9	-10	11	12	13	1.4	15	16	.17	18	19	20	51	22	23	†
Alpaugh	Wells & C.V.P.	7,573	6,608					12,000	5,720	2.10	11,167	5,420	2.06	10,220	5,420	1,88	11,310	5,590	2.02	13.823	6,500	2.13	14,293	7,000	51:
Alta	Kings River & C.V.P.	185,045	97,397	1.90	155,361	83,990	1.85	207,000	97,198	2,13	85,000	97,198	.87	126,891	109,230	1.16	99,383	109,230	.91	231,897	110,103	2.11	104,600	110,103	3
Banta-Carbona	San Josquin River,		1	1	1					1 -							,						,		. I
	wells & C.V.P.	34,817	16,900			17,287	2.49	37,997	14,529	2,41	46,022	15,118	3.04	42,542	18,154	2.34	43,791	17,617	2.48	33,831	17,570	1.92	39,382	14,491	ı I
Corcoran	Kings River & wells	54,039	29,960	1.80	68.786	35,165	1.96	61,326	34,400	1.78	44,675	34,525	1.20	48,025	33,200	1.45	47,014	31,415	3.50	41,443	41,443	1.00	40,468		
Delano-Earlimart	Wells & C.V.P.	151,834	49,374		157,591	48,742	3,23	162,613	49,635	3.27		35,000	2169	96,893	35,000	2.77	67,277	20,321	2 22	52,412	15,000	3.49	26,509	43,534	
Exeter	Wells & O.V.P.	22,538	11.805	1 01	19,470	12,539		19,503	11,754	3.66	34,105	11,975		33,710	11,834		33,504	11,796	3.37	32,302	11,806		6,220	11,000	41
Freung	Kings River, wells &	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	22,000	~17.	201410	22,739	4.77	191703	773 (34	1.00	34,105	17,915	2,05	22, (TO	11,034	2,05	33,704	11,190	2,04	32,302	ш,оо	6.74	0,220	11,000	4
	0.V.P.	417,138	100 766	0 16	313,166	192,746	2 62	560,891			366,896	172,472	2.13	407,581	171,900		403,323	171,900		543,162	169,800		449,259	169,800	
James	Presno Sloush, wells	4213200	130) 140	2.120	343,400	192,140	1.05	200,091			300,090	1.45%4.45	2,13	407,501	171,900	2,37	403,323	171,900	2,35	543,102	169,000	3.20	449,259	169,000	4
-	& C.V.P.	48.043	20,102	0.20	67,460	20,210	0.01	/								1	40.0								-1
Lanus	Kings River & vells	38,823	26,278	2.39		20,210	3+34	61,195	19,422	3.15	70,000	18,424		76,681	20,243	3.79	68,456	18,195	3.76	57,442	15,340	2.98	48,318	16,917	41
Lindnore	Wells & C.V.P.	44,468			51,000	34,000	1.50	61,291	34,000	1.80	7,000	25,000	.28	25,019			50,618	25,309	2,00					30,000	21
Lindsay-Strathmore	Kawesh River, wells	44,400	23,507	1.09	48,239	24,969	1.93	46,887	23,972	1.96	52,082	24,133	2.16	47,640	24,242	1.96	44,070	25,149	1.75	34,655	23,538	1.47	8,120	21,700	2
FIRMWA-Selectmoie	& C.V.P.												. 1			1 1							l	1	- 1
Lower Tule		23,380	11,758		24,119		2.18	22,257	10,854	2,05	23,615	10,459	2.26	22,628	10,513	2.15	19,662	9,988	1.96	17,405	9,521	1.83	19,117	9,465	
Madera	Tule River & C.V.P.	111,766	80,163	1.39	124,158	77,722	1.60	108,786	79,852	1.36	101,066	81,107	1.25	89,066	75,051	1,89	90,000	77,848	1.16	76,000	77,661	.98	40,000	60,436	5
Madera	Freeno River &		l .	1						l .			1 1												-
	C.V.P.	87,007	85,871	1.01	82,836	87,534	+95	73,789	91,054	.81	60,958	91,679	.66	47.639	91.031	.52	42,413	91,223	.46	46.862	85,240	-55	18.046	88,688	3 I
Moroed	Maroed River & wells	461,800	105,997	4.36	502,000	111,445	4.50	500,900	112,283	4.46	443,550	110,263	4.02	440,250	106,814	4.12	514,200	108,945	4.72	426,700	113,408	3.76	445,800	115,531	ıΙ
Modesto	Toulumne River &								- ,						,		,,					0	,,		
	Wells	215,100	67,522	3.18	244.600	67,361	3.63	242,900	67,370	3,60	247,100	77,114	3,20	263,900	70.237	3.33	258,550	76,108	3,40	229,900	76,594	3.00	245,670	68,918	al
Porterville	Tule River & C.V.P.	5,385	13,089	.41	3,940	13,549	129	3,979	13,980	.28	4,030	14,672	.27	2,738	14,147	.19	5,304	14,230	.37	4,137	14,410	.29	4,110	14,351	
Riverdale	Kings River	49,814	10,350	4.81	10,778	10,460	1.03	42,248	11,050		34,000	12,990		35,000	12,900		47,500	12,004	3.96	25,000	13,380		-7,220	13,380	
Tranquility	Fresno Sloush, wells	.,,,	,5,		/110	20,100	2100	10,010	22,0,0	3104	34,000	76,550	8,02	3,,000	22,500		413,000	22,004	3.50	2,,000	25,500	1101		25,500	1
	& C.V.P.	35,838	5,231	6.8s	34,696	7,581	4.58	34,139	8.845	3.86	33,916	8,289	4.09	45,343	9,141	4,96	46,022	8,674	5,30	43,751	8,001	5.47	40,698	8,112	٠L
Tulare	Kawesh River &	337434	//	0107	349090	13,002	4.50	34,139	0,045	3.00	33,910	0,209	4.09	92,393	9,141	4.90	40,022	0,014	2+30	42) (27	0,001	2.41	40,090	0,112	-
	C.V.P.	131,610	62,509	9.10	95,557	64,069	1.49	117,500	11 010		100,000	CC-			C1 C-0	l l		c- 1/-			ee			1/ 000	
Turlock	Toulumno River &	22,010	06,709	2.10	923221	04,009	1.49	TT/2500	00,349	T-77	100,000	65,082	1.54	99,157	64,692	1+53	120,771	67,465	2.35		66,313		76,956	66,313	3
	wells	442,301	260 100	0 00	512,952	260 000		1 0						10-06		1			l l						. 1
Waterford	Toulumne River	32,395	102,439	8.72	32,460	161,899	3.17	491,826	161,462	3.05	441,820	181,147		487,869	187,454			181,808		454,754	182,536	2.49	464,692	163,731	
Westside	San Josquin River,	36,399	0,057	4.70	52,460	6,952	4.67	35,403	6,910	5,12	29,562	7,172	4.12	33,991	7,368	4.61	35,393	6,989	5.06	35,064	6,815	5.14	32,785	6,700	21
Meacaide	Ban Joaquin Hiver,			1				. 1																	.1
West Stanislans	wells & C.V.P.	28,937	9,232	3.13	32,265	9,647	3.34	29,635	9,887	3.00	32,143	10,881	2.95	29,053	10,933	2,66	29,590	10,534	2.81	24,159	10,904	2,22	26,844	11,286	5
West Stanislaus	San Josquin River,																								- 1
1	wells & C.V.P.	58,067	23,471	2.47	77,216	23,228	3.32	69,307	23,344	2,97	68,994	23,639	2.92	68,923	24,633	2,80	72,474	23,868	3.04	59,993	24,495	2.45	66,642	24,862	21

a/ Prior to 1956, it was not possible to separate out double crop acreage from the crop report.

Source: Report on Irrigation and Water Storage Districts in California for 1951-1955 and 1956-1958. Bulletin 21, California State Department of Water Resources.

Surface Irrigation Water Costs 1

Investment

Investments in the distribution system for delivering water to farm headgates is one of the most important factors affecting the cost of water to farmers.

The magnitude of such investments varies, in turn, according to design and construction methods. Distribution systems may range from unlined ditches to reinforced concrete pipelines delivering water under pressure to farm headgates.

Water losses are high in unlined ditches, due to seepage and evaporation. Total
losses for some distribution systems may exceed 50 percent, according to considered estimates. Seepage losses are not complete losses, of course, if the
water percolates down to recharge underground basins. If, however, an imperivous
soil layer lies close to the surface of the ground these seepage losses can
create severe drainage problems.

Concrete pipeline or concrete-lined ditches reduce seepage losses considerably, but are very costly. In spite of the cost element, however, and even where drainage problems do not exist, distributing agencies are using pipelines and lined canals increasingly during recent years. Thus, they substitute capital resources for the more expensive water resource, the result is to increase fixed costs, but to save the variable costs represented by lost water.

A second factor affecting distribution system cost is the size of the service area per turnout. If a distribution system is designed for delivering water to each 40-acre percel of land in a district, it will require many more miles of ditches or pipeline than a system delivering water to each 160-acre area. A comparison of California districts underscores this point. Two irrigation distribution systems constructed during the 1950-1960 period with each turnout serving

^{1/} Many excellent articles and bulletins have been written on this subject. For a few examples, see Brewer, M. F., Water Pricing and Allocation with Particular Reference to California Irrigation Districts, Berkeley: University of California, Agr. Exp. Sts., Giannini Foundation Mimeo. Rept. No. 235, October 1960, and Economics of Public Water Pricing, Giannini Foundation Research Rept. No. 244, May 1961.

160 acres report investments per-acre-served of about \$130 and \$185, respectively. These were closed type systems with a capacity of one cubic foot per second for each 75-80 acres. In contrast, two other systems built during the same period with turnouts for each 80 acres, and the same capacities, invested about \$250 and \$280 per acre served. Such wide differences should not always be expected. Other cost-affecting elements, such as construction methods and materials, topography, and right-of-way costs, might offset or widen them. These examples do give some indication of how variations in the ratio of turnouts to area, affect the magnitude of costs involved.

Irrigation districts and other distributing agencies perform services other than delivering water to farm headgates. Some organizations have developed expensive drainage facilities for all or parts of their service areas. This service may involve constructing drains, deepening ditches, building and operating pumps to carry off excess water accumulating at lower elevations. Other services include constructing and operating water spreading facilities, generating and distributing electrical power, and providing telephone service.

Irrigation districts and other organizations holding contracts with the agency pay the U. S. Bureau of Reclamation for water they obtain from this source. Long-term contractors pay \$3.50 per acre-foot for Class I water from the Friant-Kern and Madera canals. The price for Class II water is \$1.50 per acre-foot. Class I water represents the basic or firm water supply and Class II the surplus. Each water sales contract specified minimum quantities of each class that the contractor must take if this water is available. Distributing agencies taking irrigation water from the Delta-Mendota Canal pay a canal-side price of \$3.50 per acre-foot for any and all water.

Operating Costs

Operating costs for irrigation districts vary widely. Administrative, operating and maintenance costs, in a sample of 21 irrigation districts, ranged from \$0.94 to \$7.76 per acre-foot for water delivered to farm headgates. To make

the comparison as direct as possible, pumping costs and outlays for purchased water are not included in these figures. The mean cost per acre-foot delivered was \$1.81.

The smaller districts in terms of water delivered usually had the highest costs, while the districts delivering the larger quantities of water generally showed lower costs. These quantities of water delivered do not include water spread by the districts for recharging underground basins.

Our cross section sample of irrigation districts is not sufficiently homogeneous to support statistically significant generalizations as to how size relates to costs in distributing surface irrigation water (see Table 12). Operating expenses for irrigation districts with unlined canals and laterals differ widely from districts with completely closed concrete pipelines. Also, some of these districts operate drainage facilities for parts of their service areas, whereas others do not. A multiple regression equation fitted to these data with cost per-acre-foot as the dependent, and gross service area and total water delivered as the independent variables, did not explain a significant amount of the cost variations.

How Suppliers Price Water

Agencies supplying irrigation water may levy charges and obtain revenue to cover their costs in various ways. The law prescribes or delimits the methods that some distributing agencies may use. Irrigation districts, for example, have the power as public entities to issue bonds and to assess and collect taxes on land. The law does not give this power to private water companies, or to mutual water companies. Private water companies come under the public Utilities Commission, and usually use a metered toll rate. Mutual water companies generally collect their revenue from assessments on stock in the company; sometimes they use a metered toll in addition.

TABLE 12
Operating Expense for Irrigation Districts, 1958

	Gross							Cost
	service						Water	per
	area in	1				Total	delivered	
District	acres	Admin.	Wages	Mat.	Other	Cost	acre feet	
	1	2	3	4	5	6	7	8
Alpaugh Alta Central California Consolidated	8,131 129,300 154,100 155,000	14,652 91,989 94,464 72,666	18,120 91,332 191,268 90,899	6,856 30,461 93,932 24,801	19,135 119,327 63,190 122,893	58,763 333,109 442,854 311,259	185,045 377,454	7.76 1.80 1.17
Corcoran Delano-	51,600	11,788	44,512	76,516	55,934	188,750		3.49
Earlimart Exeter Fresno Ivanhoe James Lindmore Lindsev-	56,594 14,638 235,520 10,887 25,836 27,267	29,072 34,007 161,819 26,573 32,112 44,402	43,200 13,686 403,134 12,416 33,466 58,881	14,708 10,499 72,095 389 34,951 15,945	85,033 15,897 303,314 4,937 13,386	172,013 73,888 637,048 44,315 113,915 119,228	22,538 417,138 14,707 48,043	1.13 3.28 1.53 3.01 2.37 2.68
Strathmore Lower Tule Medera Merced Porterville Saucelito Shafter-	15,440 103,087 112,250 163,384 17,127 19,326	28,449 53,089 96,893 181,632 22,155 16,167	64,898 40,687 114,506 426,781 3,663 10,938	44,682 10,287 52,539 178,973 349 455	41,974 66,397 2,527 127,915 3,578	180,003 170,460 266,465 915,301 29,745 27,560	111,766 87,007 461,800 5,385	7.70 1.52 3.06 1.98 5.52 1.53
Wasco Tranquility Tulare W. Stanislaus TOTAL	37,528 10,750 75,121 22,429	40,116 22,815 47,950 21,854	23,725 19,224 102,280 111,135	2,366 9,449 81,412 60,320	4,193 36,964 1,178 11,190	70,400 86,452 232,820 204,499 14,678,847	35,838 131,610	2.14 2.41 1.77 3.52 1.78

Source: Annual Report of Financial Transactions Concerning Irrigation Districts of California, 1958; and California Department of Water Resources, Bul. 21, Report on Irrigation and Water Storage Districts in California for 1956-1958, March 1960.

Irrigation districts, the agencies delivering the larger quantity of all water, use a variety of methods to obtain revenue. Most common among these is a tax assessment combined with a metered toll charge; many use only the assessment. Some districts levy a flat rate per acre of crops irrigated, varying the rate according to crops grown.

Some irrigation districts vary metered toll rates within their service areas.

Those with portions of their service areas significantly higher in elevation than
the source of supply may charge higher toll rates in such localities to cover
added costs for lifting the water to the higher elevations.

Annual assessments per acre also may vary within a district, even for land of uniform valuation. Such variations in levy on uniform quality land may be applied in some parts of a district to recover the costs for local drainage or canal improvements.

If we impute a water user's total payments as costs for direct deliveries of irrigation water, the result is to mask the cost and value of other services that the distributing agency provides. Thus the agency may spread water or operate drainage facilities with important benefits to the water user, and look to these payments for reinbursement.

A farmer within an irrigation district may regard the annual assessment portion of the total cost for surface water as a fixed cost. He must pay this amount even though he receives no water during the year. This fixed portion reacts sharply on the average total cost per acre-foot of water when year-to-year quantities fluctuate, as between wet and dry years. This fixed portion of the total cost must be spread over relatively fewer acre-feet per acre delivered in years of short supply.

The metered toll rate, if used, represents the variable cost portion of the total payment complex; the purchaser pays it only when the agency delivers water. Data available for 11 irrigation districts are helpful as indicators of how variations in annual water deliveries affect average total costs to users (see Table 13). We selected these districts according to geographic location, and because data were available regarding their operations; we do not consider them a representative sample. The water delivery data include the wet year, 1957-1958, (annual runoff about 125 percent of normal) and the dry year, 1953-1954 (annual runoff about 75 percent of normal).

An irrigation district does not always reduce the quantities of water that it delivers to its users within the district during a dry year, as compared with a wet one (see Table 13). A particular district may have sufficient storage carryover from the previous year to meet needs in a dry year, or it may divert water from its normal ground water recharge program and use it to maintain or increase direct irrigation deliveries.

TABLE 13

Quantity and Cost of Surface Irrigation Water Delivered in Wet and Dry Years for 11 Irrigation Districts; San Joaquin Valley Cotton Area

District	Assess- ment per \$100 valu- ation	Typical valua- tion per acre dollars	Assess- ment per acre	per irr. Wet year	delivery acre Dry year feet	Average a per acre- (fixed co Wet year	Dry year	Typical toll rate per ac. ft. (variable cost) llars	Total per a Wet year	cost c. ft. Dry year
1 2 3 4 5 6 7 8 9 10	4.25 4.00 1.50 7.00 3.25 5.00 3.16 5.70 3.86 3.50 6.50	100.00 100.00 100.00 140.00 50.00 100.00 200.00 110.00 100.00	4.25 4.00 1.50 9.80 1.62 5.00 6.32 6.27 4.44 3.50 6.50	1.90 3.50 1.23 3.08 2.39 2.47 1.86 1.39 1.00	.87 1.51 1.29 2.82 3.80 2.13 2.16 1.25 .66 1.56 1.54	2.24 1.14 1.22 3.18 .68 2.02 3.40 4.51 4.44 2.57 3.19	4.88 2.65 1.16 3.48 .43 2.35 2.92 5.02 6.73 2.24 4.22	0 0 5.50 2.00 4.50 0 5.00 3.00 2.60 4.50 2.00	2.24 1.14 6.72 5.18 5.18 2.02 8.40 7.51 7.04 7.07 5.19	4.88 2.65 6.66 5.48 4.93 2.35 7.92 8.02 9.33 6.74 6.22

Source: Report on Irrigation in Water Storage Districts in California, California Department of Water Resources, Bulletin 21 and Survey of Irrigation Districts.

APPENDIX TABLE 1

Schedules for Electrical Energy Rates

A. Pacific Gas and Electrica/

	rate per kwh.	e in addition for consumption	to the service	charge r year of
0	Annual service	First	Next	All over
Connected load horsepower	charge per hp.	1000 kwh.	1000 kwh.	2000 kwh.
			Ce	nts
2 to 4.9 ^b /	8.83	1.85	.91	.65
5 to 14.9	7.46	1.59	.91	.65
15 to 49.9	6.73	1.49	.91	.65
50 to 99.9	5.99	1.38	.91	•59
100 to 249.9	5.26	1.33	.91	•59
250 to 499.9	5.26	1.28	.91	•59
500 to 999.9	5.05	1.22	.91	•59
1000 to 2499.9	4.73	1.22	.91	•59
2500 and over	4.20	1.22	.91	•59
	B. Southern Ca.	lifornia Edisor	,c/	
2 to 4.9	9.00	1.86	.82	.64
5 to 14.9	8.00	1.66	.82	.64
15 to 49.9	7.50	1.56	.82	.64
50 to 99.9	7.00	1.46	.82	.64
100 and over	6.50	1.36	.82	.64

Minimum charge: The annual minimum charge shall be the annual service charge.

a/ Revised Cal. P.U.C. Sheet No. 2891-E.

b/ In no case will the total annual service charge nor the energy charge be based on less than 2 hp. for single-phase service, nor less than 3 hp. for three-phase service.

c/ Revised Cal. P.U.C. Sheet No. 2811-E.